An Integrated Approach to Maintenance in a Three-Crew, Two-Shift Environment

by
Anthony J. Kramer

B.S. Mechanical Engineering,
Michigan State University, 1990

Submitted to the Sloan School of Management and the
Department of Mechanical Engineering
in Partial Fulfillment of the Requirements for the Degrees of

Master of Science in Management
and
Master of Science in Mechanical Engineering
at the
Massachusetts Institute of Technology
June 1997

Signature of Author: ______________________________
Sloan School of Management
Department of Mechanical Engineering

Certified by: ______________________________
Janice A. Klein, Thesis Advisor
Senior Lecturer, Sloan School of Management

Certified by: ______________________________
David E. Hardt, Thesis Advisor
'rofessor, Department of Mechanical Engineering

Accepted by: ______________________________
Lawrence S. Abeln, Director of Master's Program
Sloan School of Management

Accepted by: ______________________________
Ain Sonin, Chairman
Committee on Graduate Students, Mechanical Engineering

An Integrated Approach to Maintenance in a Three-Crew, Two-Shift Environment

by

Anthony J. Kramer

Submitted to the Sloan School of Management and the Department of Mechanical Engineering in Partial Fulfillment of the Requirements for the Degrees of

Master of Science in Management
and
Master of Science in Mechanical Engineering
June 1997

Abstract

In an effort to more fully utilize its assembly plant facilities, General Motors has recently implemented a production schedule known as Three-Crew, Two-Shift in a few of its assembly plants. This new schedule utilizes three crews of workers to staff two ten-hour shifts of production, running six days per week. To varying degrees, each of the three-crew, two-shift assembly plants have all had trouble adjusting to the demands of the new system; especially in the area of equipment maintenance. The reason for this difficulty in the maintenance arena is twofold: first, the equipment is used more than it has been in the past so it sustains more wear and tear; and second, the additional production reduces the equipment idle time that maintenance has available to work on the equipment. From the perspective of the maintenance organization, three-crew, two-shift means that there is more work to do, and less time to do it.

The central issue of the internship project was to resolve the body shop equipment maintenance problems associated with three-crew, two-shift. The objective was to determine what changes need to be implemented to the "system" in order to ensure reliable equipment performance in a body shop running this type of extended schedule. Typically, this type of problem has been attacked on a technical front, with solutions such as adding spare equipment or increasing buffer sizes. Although these solutions can help plant management cope with daily problems in the short term, they do not address the root cause of the problem, so they cannot be expected to work as the long term answer. This thesis will argue that in order to eliminate these issues, the organization must change the way that it approaches problem solving. A more complete, long term solution can be developed by taking an integrative approach that considers people issues, business processes, and technology systems. Looking at the problem from the perspective of all three systems will help produce a final solution that more fully addresses the problem.

Thesis Advisors:
Janice A. Klein, Senior Lecturer, Sloan School of Management
David E. Hardt, Professor, Department of Mechanical Engineering

Acknowledgments

First of all, I gratefully acknowledge the support and resources made available to me through the MIT Leaders For Manufacturing Program, a partnership between the Massachusetts Institute of Technology and major U.S. manufacturing companies. I would also like to acknowledge resources made available to me by the General Motors Corporation.

I would like to acknowledge my advisors, Professor Dave Hardt form the Department of Mechanical Engineering, and Sr. Lecturer Jan Klein from the Sloan School. I want to thank each of them for their suggestions and guidance throughout the entire project.

I would also like to acknowledge the many people at General Motors who helped me throughout the internship project. A special thanks goes out to all of the plants that I visited: Lordstown, Saturn, Moraine, Antwerp, Orion, and Detroit-Hamtramck. The knowledge and insights that I gained from the plant visits were some of the most valuable lessons that I learned from the internship experience. In addition, I would like to thank my internship supervisor, Les Jones, for his guidance and insights throughout the project.

Finally, I would like to thank my family. To my parents, for their support and guidance throughout my life. To my daughter, Kaitlin, for helping me remember to appreciate the simple pleasures in life. And most of all, I would like to thank my wife, Teresa, for her patience, love and support. She has helped me keep my priorities straight and maintain my sanity during these somewhat stressful past two years. Thank you T.

An Integrated Approach to Maintenance in a Three-Crew, Two-Shift Environment

Table of Contents

ABSTRACT **3**

ACKNOWLEDGEMENTS **5**

TABLE OF CONTENTS **7**

LIST OF FIGURES **9**

CHAPTER 1: INTRODUCTION **11**

1.1 INTRODUCTION 11
1.2 GENERAL PROBLEM 12
1.3 INTEGRATION FRAMEWORK 12
1.4 PROBLEM SOLVING METHODOLOGY 14
1.4.1 Step 1: Identify the Problem *15*
1.4.2 Step 2: Collect and Analyze Data *16*
1.4.3 Step 3: Determine Root Causes *16*
1.4.4 Step 4: Develop Integrative Solution *17*
1.4.5 Step 5: Implement Solution *17*
1.4.6 Step 6: Evaluate Effects *18*
1.4.7 Step 7: Standardize Solution & Reflect on the Process *18*
1.5 THESIS OVERVIEW 18
1.6 RESEARCH METHODOLOGY 20

CHAPTER 2: BACKGROUND **23**

2.1 AUTOMOBILE ASSEMBLY PROCESS 23
2.2 THREE-CREW, TWO-SHIFT 24
2.3 PROJECT DESCRIPTION 26

CHAPTER 3: INTEGRATIVE APPROACH TO THE MAINTENANCE DILEMMA **29**

3.1 IDENTIFY THE PROBLEM 29
3.2 COLLECT AND ANALYZE THE DATA 32
3.2.1 Lordstown *32*
3.2.2 Saturn *35*
3.2.3 Moraine *37*
3.2.4 Common Problems *39*
3.3 DETERMINE THE ROOT CAUSES 41
3.3.1 Business Processes *43*
3.3.2 People Issues *45*
3.3.3 Technology Issues *46*

3.3.4 Root Causes *47*
3.4 Develop Integrative Solution 47
3.4.1 Total Productive Maintenance *47*
3.4.2 Quality Network Planned Maintenance *51*
3.4.3 Antwerp's Transition to Planned Maintenance *53*
3.5 Implement Solution 59
3.5.1 Resistance to Implementation *59*
3.5.2 Overcoming the Resistance *61*
3.6 Evaluate Effects of Solution 62
3.7 Standardize The Solution and Reflect on Process 63

CHAPTER 4: CONCLUSIONS AND RECOMMENDATIONS 65

4.1 Summary of Results 65
4.2 Three-Crew, Two-Shift Recommendations 66
4.2.1 Proposed Three-Crew, Two-Shift Schedules *66*
4.2.2 Body Shop Operating Philosophy *70*
4.2.3 Maintenance Organization *71*
4.2.4 Maintenance Practices *72*
4.2.5 Re-engineering the Equipment *74*
4.3 Conclusions 75
4.4 Final Comments 75

BIBLIOGRAPHY 77

APPENDIX A: THE PRINCIPLES OF THE FIVE S'S 79

APPENDIX B: GM-UAW QUALITY NETWORK PLANNED MAINTENANCE 80

List of Figures and Tables

Figure 1.1 The Three Key Management Systems 13
Figure 2.1 Assembly Process Flow 23
Figure 2.2 Basic Three-crew, Two-shift Production Schedule 24
Figure 3.1 Goals of World Class Maintenance 30
Figure 3.2 Downtime vs. Repair time 32
Figure 3.3 Lordstown Production Schedule 33
Figure 3.4 Lordstown WEMR Schedule 34
Figure 3.5 Lordstown Maintenance Organization 35
Figure 3.6 Saturn Production Schedule 35
Figure 3.7 Saturn Body-Fab Maintenance Organization 36
Figure 3.8 Moraine Production Schedule 37
Figure 3.9 Moraine Body Shop Organization 39
Figure 3.10 Possible Causes of Excessive Downtime 42
Figure 3.11 Toyota Production System and TPM 50
Figure 3.12 Antwerp's 3-Crew/2-Shift Production Schedule 54
Figure 3.13 Antwerp's 3-Crew/2-Shift Maintenance Schedule 54
Table 3-1 Root Causes and Key Elements of QNPM 62
Figure 4.1 Proposed 3C/2S Production Schedule 66
Figure 4.2 Proposed Maintenance Schedule 69

Chapter 1: Introduction

1.1 Introduction

During the past decade, books such as *Made in America*, and *The Machine that Changed the World*, have exposed the gap in competitiveness between Japan and the US. This has forced American industry to concentrate on improving their manufacturing operations. The introduction of the Toyota Production System and concepts such as "Just-In-Time" and "Lean"[1] changed the rules for how to compete in today's competitive manufacturing environment. In this new environment, manufacturing excellence has become a requirement for business success. World Class Manufacturing has become the goal of every manufacturing manager. What does "World-Class" mean, and what does it take to achieve this World-Class status?

Simply put, "World-Class" means being the best in your field in the world. "Best" can be defined in terms of Quality, Cost, Lead times, Safety, Customer Service, or many other categories. World-Class Manufacturing is frequently used as an umbrella term covering all of these categories and more. A world-class manufacturing enterprise, such as Toyota, recognizes the importance of improving the whole manufacturing system rather than focusing on only one or two categories. This emphasis on the whole system is what sets apart a truly world-class organization from its competitors.

Most managers recognize the competitive advantage that manufacturing excellence can provide a company, but they are not sure how to get there. A company like Toyota performs at such a high level because they have learned to balance the people systems, business processes, and technology within their manufacturing system. Integration of these three sub-systems is essential to achieving world-class status. The objective of this thesis is to explore this issue of integration and show why it is important. The analysis of this internship project should demonstrate the value of an integrated approach to problem solving.

[1] Womack, Jones, and Roos. *The Machine That Changed the World.* New York: Harper Perennial, 1991.

1.2 General Problem

In general, when approaching a problem, companies tend to concentrate on either the technical solutions, business practices, or people issues. Occasionally, two of these different areas are addressed but rarely are all three considered. If one or two of these areas are ignored while addressing a problem, the resulting solution will be sub-optimal. This is not to say that some problems cannot be solved with a purely technical or people oriented solution, but the solution could be enhanced by considering the other issues while developing the solution.

A common error in American companies is the tendency to immediately focus on a technical solution. Companies with a history of technical innovations, or those that have been lead by engineers and technologists will most likely rely on their perceived strength: technical solutions. This tendency is understandable because technical solutions are frequently seen as more glamorous and more sophisticated, and therefore better. Sometimes though, the technical challenge of trying to solve a problem can overshadow the actual problem, resulting in technology for the sake of technology. The best answer is to uncover the root problem and then address it with the simplest approach that will work, whether it be technology, people, or a change in business practices.

1.3 Integration Framework

In the book, *The People Dimension: Managing the Transition to World-Class Manufacturing*[2] the authors, Recardo and Peluso, assert that every manufacturing business has three main areas that it must manage. They refer to these areas as management systems: technology, people, and business management systems (figure 1.1). As the figure indicates, although each of the systems can be examined separately, they are interconnected and they overlap. Any event that impacts one of the systems will have some effect on one or both of the other two systems. World Class manufacturing can only occur within an organization when all three of these systems are integrated.

---

[2] Recardo, Ronald J., and Luigi A. Peluso. *The People Dimension: Managing the Transition to World-Class Manufacturing.* White Plains, NY: Quality Resources, 1995.

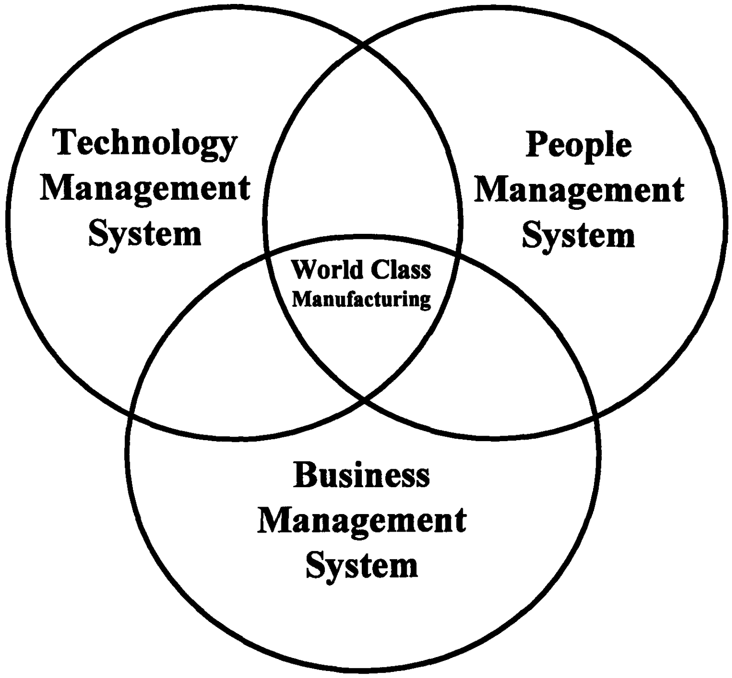

Figure 1.1 The Three Key Management Systems [3]

Recardo and Peluso define the three management systems as follows:

Technology Management Systems

Technology management systems are the provisions that assist the people in the organization. They allow the proper application of equipment, processes, and appropriate facilities to accomplish the goals and objectives outlined in the company's business plan. Examples of such systems would include: manufacturing cells, computer-aided design and manufacturing equipment, materials requirement planning systems, quick changeover machinery, and production lines. The systems are designed to improve the speed and reliability with which people can perform their functions. The key to success is trying to assist, as opposed to displace, the people within the organization.

People Management Systems

People management systems are those activities, practices, and procedures that will empower the company's people. They provide the direction and challenge in the development of people. These systems assist the employees in the application of available and affordable resources

[3] Recardo & Peluso. (1995)

toward the achievement of the company's business plan. Included in such systems are employee education programs, focused involvement teams, and self-directed work groups. These systems are meant to reduce the red tape and allow decision making to be leveraged and made at the lowest level that is realistically possible.

Business Management Systems

Business management systems are the company's practices, policies, and procedures. They plan and direct the activities of the organization's personnel in applying company resources to satisfy customer requirements. These systems include a company's compensation and reward system, organizational structure, distribution systems, and management of the supply chain. Business management systems are critical because no company has unlimited resources. The winners in manufacturing are those who understand how to maximize the amount of value they add while minimizing the resources they require to add this value. The most precious resource in today's manufacturing and business world in general is time.

Balancing the Systems

Each of the three systems has an important objective. The objective of the technology management system is to achieve a highly flexible production environment through technical innovation. The people management system needs to provide the capability for rapid improvement and adaptation to change. The objective of the business management system is to carefully apply the organization's limited resources; capital and hard assets, as well as time and human assets. To optimize total output, the organization must recognize the importance of each of the three systems, and balance the needs of each. A World Class manufacturing organization is one that understands the system interactions and has learned to integrate the three systems within its operations.

1.4 Problem Solving Methodology

The following section outlines the structured problem solving methodology that will be used to analyze the internship project. The methodology follows Total Quality Management principles and is based on the 7-Step model from *A New American TQM* by Shoji Shiba. The use of this structured methodology will help to develop an integrative solution by providing the discipline required to find the root cause and systematically consider all feasible solutions.

1.4.1 Step 1: Identify the Problem

Although this step may sound simple, identification of the problem is the most important aspect of reactive problem solving. It is also the step that is most often neglected by problem solvers. Failure to properly identify the problem will cause problems later in the process, and lead to wasted time and energy.

The first aspect of problem identification is to look at the situation from a weakness orientation. Weakness can be defined as the difference between the current state and your desired state. The weakness orientation focuses attention on improvement of the problem. It helps focus on the process, not the results. The results are the effect; the process is the cause. A weakness orientation also encourages an objective analysis of causes ("what caused the downtime?"), rather than jumping directly to solutions ("what can we *do* to improve?"). A weakness orientation is the most important component of problem identification.

The next element of problem identification is to explore the problem thoroughly. There are many problems that you can work on, but which one is most important? The key here is to focus on your customer. Consider the *5 Evils*[4] -- defects, mistakes, delay, waste, and accidents or injury -- to focus attention on a theme directly related to customer satisfaction. The 5 Evils always cause customer dissatisfaction or excessive cost. Thorough problem exploration is necessary to ensure that you are not wasting resources on a non-vital problem.

The final step of problem identification is to clearly state the theme. A clear theme is important because it will become the mission of the problem solving team. The theme must be stated as a problem, not a solution; and it must focus on a single problem, not several. The theme must have a weakness orientation, and focus on the needs of the customer. When choosing the theme, you must consider the interests of the customer and understand why solving this problem is important to the customer. Then you can be sure that you are addressing the

[4] Shiba, Graham, and Walden. *A New American TQM: Four Practical Revolutions In Management.* Portland, OR: Productivity Press 1993.

customer's needs. Having a carefully selected, clearly stated theme is essential to a successful problem solving process.

1.4.2 Step 2: Collect and Analyze Data

The second step of the problem solving process starts with collecting the data. The key here is to look for information that will give you insight into the problem. Improve your understanding of the problem by "jumping into the fishbowl"[5] to see the problem from the customer's perspective. This will help you understand the process that you are working with and point to sources of information. It is important to remain objective during data collection; to focus on facts, not opinions. Examine existing data collection systems carefully before using the information. It is better to design a new system specifically for your problem solving efforts rather than struggle with the flaws and assumptions built into someone else's system. Understand that there are many sources of relevant data to explore. For some problems workforce interviews and personal observations from plant visits can give more information than reams of numerical data. Thorough data collection is essential to discovering the root cause of the problem.

Data analysis is the process of putting all of the information together logically so that it can be interpreted. Data collection and analysis are done together in an iterative fashion. After the data is collected, it is compiled, and examined in order to determine if further data collection is required. Pareto diagrams, histograms, and cause-and-effect diagrams are some of the available tools to help complete the analysis process. The product of this step is a collection of organized information that point toward several possible causes of the main problem.

1.4.3 Step 3: Determine Root Causes

The objective of step three is to use the newly acquired data to determine the root cause of the problem. Once the root cause is found the solution should be clear – reverse the root cause. Therefore, it is important that the real root cause of the problem be uncovered, not just one of the many symptoms. The most helpful tool for this step is the Cause-and-Effect, or Fishbone

---

[5] Shiba, Graham, and Walden. (1993)

diagram introduced in Japan by Dr. Kaoru Ishikawa in 1943. A Cause-and Effect diagram can help develop a thorough analysis of the problem by giving a visual representation of the possible causes so that the relationships between them can be identified more easily. The branches on the diagram are created by answering the question, "Why this result?", for each suspected cause. The root of the problem can be found by focusing on the causes that the data show are most influential. Once the root cause is uncovered and understood you can move forward to the next step.

1.4.4 Step 4: Develop Integrative Solution

Once the root cause of the problem has been uncovered, a solution needs to be developed that will effectively eliminate the problem. Ideally, the solution will directly reverse the root causal mechanism. In order to arrive at the optimal solution it is important to carefully consider all feasible solutions. Look at your people and business processes before jumping to a technical solution. Often, the simplest solution can be the most effective. Do not eliminate an idea simply because it did not work as the solution to a previous problem. No two problems are exactly the same. Like the list of possible causes, the list of solutions can be numerous, so a thorough evaluation will be required to ensure the best answer.

An important resource for this step is the people who will be implementing the proposed solution. Their involvement can provide valuable input into the solution formulation and reduce the chance of resistance during implementation because they will have a sense of ownership of the solution. Stakeholder buy-in is important during the formulation stage. At the very least it is essential that the interests of the various stakeholders are known and taken into account in the solution or else you are setting yourself up for failure. Remember, even the best solutions are worthless if they cannot be implemented.

1.4.5 Step 5: Implement Solution

Most problem solving books lump implementation into the same step as planning the solution, but it has been separated into its own step here to underscore its importance. Implementation is the stage where many good solutions stall out and die. This usually happens because the stakeholders' interests were not considered during the solution development stage. It is important to consider how implementation will effect different people in order to anticipate possible resistance. It will then be possible to develop a proactive plan to reduce the resistance and help implementation proceed. Communication and education are powerful tools to use during the implementation stage to promote the new solution. Another idea is to start off by implementing the change in a pilot area first. This will minimize the initial impact and provide some tangible evidence that the idea will work before the whole organization is asked to change. Implementation is an important step that deserves a great deal of attention from the problem solving team.

1.4.6 Step 6: Evaluate Effects

After the solution has been implemented, the next step is to evaluate the solution on the basis of eliminating the problem. Collect current samples of the key data to compare with the earlier information. Has the change solved the original problem? Has this course of action created any new problems or side-effects? If the situation has improved as expected you can proceed to step seven, otherwise go back to step five to develop a new solution.

1.4.7 Step 7: Standardize Solution & Reflect on the Process

This final step requires that you reflect on the entire problem solving process and consider what you have learned. Anything that you see could have been done better should be documented and forwarded to the rest of the organization. If the solution has worked, you need to make this the new standard so that the others can benefit from your team's learning. This is a valuable step that is often overlooked by many companies. This is unfortunate because this step is where the knowledge that has been gained from the experience is transferred to the rest of the organization. To get the full benefits of the problem solving methodology, it is important to follow the process all the way through this step.

1.5 Thesis Overview

As stated earlier, the objective of this thesis is to demonstrate the value of an integrated approach to problem solving in the context of a three-crew, two-shift environment. The term "integrated" refers to the balance of technical, business, and people issues. The intention is to illustrate how the use of the structured problem solving methodology will ensure a thorough analysis of the problem, and help develop an integrated solution. The internship project will be examined under this process.

The internship project was sponsored by General Motors. The project focused on equipment maintenance requirements within the body assembly area in a vehicle assembly plant. The central issue was to resolve the equipment maintenance issues associated with the extended production schedule known as "three-crew, two-shift". The objective was to determine what changes needed to be implemented to the "system" in order to ensure reliable equipment performance in a body shop running this type of extended schedule. Typically, this type of problem has been attacked on a technical front. Solutions like adding spare equipment or increasing buffer sizes can help plant management cope with daily problems as they occur, but they do not address the root of the problem. Since they do not solve the core problem, they cannot be expected to work as the long term solution. This thesis will argue that a better solution can be developed looking at the problem from the perspective of all three systems. By taking a more integrated approach, the final solution will more fully address the problem.

A brief overview of the thesis follows:

Chapter 2: The goal of this chapter is to give the reader the background information necessary to understand the basic problem. First will be a an overview of the automobile assembly process. Next is some background information on three-crew, two-shift: what it is, where it originated, its purpose, and current applications. In addition, there will be a brief discussion about how a three-crew, two-shift schedule effects equipment maintenance. The section will end with a brief description of the internship project and the initial ideas for approaching the problem.

Chapter 3: In this chapter the maintenance dilemma posed by three-crew, two-shift schedules is examined by stepping through the seven step problem solving process outlined in Chapter 1. The first half of the analysis will focus on identifying the base problem and uncovering the root cause. The second half will concentrate on developing an integrative solution and a plan for implementation.

Chapter 4: The final chapter will start off with a summary of the thesis. The next section will outline some specific recommendations for managing maintenance in a three-crew, two-shift environment. The recommendations will be based on observed "best practices" and recognized world class maintenance principles. The chapter will end with some general conclusions drawn from the research and a few closing comments.

1.6 Research Methodology

The research for this thesis was carried out in three phases: first, a general literature search; second, plant visits and interviews; and third, more detailed research into world-class maintenance practices across several industries.

The purpose of the first phase of research was to gain better understanding of the context of the problem by getting more familiar with maintenance management and the concept of three-crew, two-shift. It was relatively easy to find information about equipment maintenance; but reference material on three-crew, two-shift was scarce. The General Motors Research library proved to be a valuable resource during this phase of the process because they were able to provide copies of GM internal reports on three-crew, two-shift implementation at Lordstown. This information provided valuable insights into the challenges that three-crew, two-shift presents with respect to equipment maintenance. The first phase of research helped frame the problem and made the plant visits more meaningful.

The second phase of research involved several visits to various General Motors assembly plants. This was an iterative process that spanned a total of five months. During this phase, a week was spent at each of the four assembly plants that operate the three-crew, two-shift schedule. In addition, several days were also spent at two assembly plants that run a traditional schedule. Over the course of the visits, all three shifts -- day, evening, and night -- were covered, as well as the weekend. The purpose of the visits was to observe how the plants managed their maintenance activity, and to document best practices and the lessons learned from dealing with three-crew, two-shift.

During the plant visits, most of the time was spent in the body shop. At each plant, a cross-section of the maintenance organization was interviewed. The purpose of the interviews was to find out how three-crew, two-shift had effected their jobs and their lives. The body shop area managers and several production supervisors were also interviewed in order to get their perspectives on the subject.[6] The objective of these discussions was to identify the adjustments they have had make in order to cope with the challenge of three-crew, two-shift. Simply spending time on the plant floor proved to be one of the most valuable sources of information during the visits. The informal, on-the-job conversations with the first-line supervisors and skilled-trades people provided valuable insights into the nature of each plant's particular problems. The plant visits helped develop a better understanding of the situation that the plants faced and how each of them had chosen to handle it.

The objective of the third phase of research was to determine how to remedy the problems encountered during the plant visits. World-Class maintenance organizations from other companies and other industries were studied in order to determine the characteristics that contribute to their success. Once these key characteristics were established, the specific tools were investigated to determine their applicability in the body shop. In addition, consideration was given to the role that Engineering can play in helping ensure equipment availability and quality by concentrating on reliability and maintainability during the equipment design phase.

[6] No UAW officials were interviewed during the visits because they took place during the GM-UAW contract negotiations. Due to the tense atmosphere surrounding the negotiations, it did not seem appropriate to bring up three-crew, two-shift issues.

Chapter 2: Background

Before the examination of the problem, some background information is needed to understand the context of the situation. The first section will provide a brief overview of the automobile assembly process. The next section will introduce three-crew, two-shift schedules and explain the effect that they have on equipment maintenance. The final section will describe the internship project and the objectives of the study. The goal of this chapter is to give the reader enough background information to understand the basic problem without getting bogged down in the details.

2.1 Automobile Assembly Process

An automobile assembly plant is typically divided into three main areas: Body Shop, Paint Shop, and General Assembly. Figure 2.1 illustrates the basic assembly process flow through each of the main areas, starting in the Body Shop. The Body Shop is responsible for assembling the stamped steel parts that make up what is referred to as the "body-in-white". The body-in-white is the basic structural shell of the vehicle. It includes the underbody, front of dash, side frames, fenders, doors, hood, and decklid or rear hatch. The completed body-in-white is then sent to a body bank where it is held until being sent to the Paint Shop. In the Paint Shop, the body is sealed, primed, and then painted. The painted body is then sent to a mix bank where the bodies are resequenced by option content to support line balance in General Assembly. In General Assembly the engine and chassis are married to the body, and the interior and exterior trim are added. After the General Assembly process, the car is complete and ready to be shipped to its final destination. The total assembly process generally takes about 20 to 30 hours from start to finish.

Figure 2.1 Assembly Process Flow

2.2 Three-Crew, Two-Shift

3-Crew / 2-Shift Production Schedule

Shifts	Sun	Mon	Tue	Wed	Thu	Fri	Sat
DAYS 6:00A - 4:00P		A	A	A	A	C	C
NIGHTS 5:30P - 3:30A	C	C	B	B	B	B	

Figure 2.2 Basic Three-crew, Two-shift Production Schedule

Three-crew, two-shift is a production schedule that uses three crews of workers to staff two ten-hour shifts of production, running six days per week (see figure 2.2). Within the automobile industry, three-crew, two-shift is a fairly new concept. It was first created by General Motors in 1988 for use at its Opel assembly plant in Antwerp, Belgium. The Antwerp plant created the three-crew, two-shift system in order to combine the production of two assembly plants, each running below their rated capacity, into one three-crew, two-shift operation.

The aim of three-crew, two-shift is to maximize the use of the plant and equipment. In Antwerp, the total operational costs dropped 20% when compared to the two-plant system, and capacity utilization jumped 44%, as the plant went from a 77 hour to 110 hour weekly schedule.[7] In an industry desperate to improve capacity utilization, three-crew, two-shift seems to be the perfect solution. Three-crew shifting can boost capacity more than 40% without adding the huge expense of new plants and equipment. For example, when Saturn switched to a three-crew, two-shift schedule in 1993, their production capacity jumped from 250,000 to 320,000 cars per year.[8] For a plant with a hot-selling model, like Saturn or Lordstown, this type of productivity boost is like the pot of gold at the end of a rainbow.

[7] Winter, Drew. "Bending Time: Three-crew Schedules Put an All New Face On the Clock", *Ward's Auto World.* May 1995, pp. 34-36.
[8] "GM Could Produce 6 Million Vehicles", *Ward's Auto World.* September 1993, p25.

Three-crew, two-shift is currently being used at four automobile assembly plants in the United States. General Motors is running three-crew, two-shift schedules at three of its assembly plants: Lordstown, OH, Spring Hill, TN (Saturn), and Moraine, OH. In addition, Ford recently adopted the schedule at its Michigan Truck assembly plant in Wayne, MI. Among the GM plants, Lordstown was the first to implement the three-crew concept in 1992, followed by Saturn in 1993, and Moraine in June of 1995. Although each of the plants has implemented three-crew, two-shift with a slightly different schedule, they have all had trouble adjusting to the demands of the new system; especially in the area of equipment maintenance.

The reason for this difficulty in the maintenance arena is twofold: first, the equipment is used more than it has been in the past so it sustains more wear and tear; and second, the additional production reduces the equipment idle time that maintenance has available to work on the equipment. Traditionally, a daily eight-hour shift and two days each weekend have been available for routine maintenance work and special projects. With three-crew, two-shift, the total amount of scheduled idle time is reduced to four hours per day and a twenty-four hour block on the weekend. The decrease in maintenance time from 88 hours to 48 hours is a 45% reduction in scheduled equipment idle time. So from the perspective of the maintenance department, three-crew means that there is more work to do, and less time to do it.

The purpose of this project was to determine what can be done to help maintain the equipment in a plant operating with this type of schedule. In the past, running only 80 of 168 hours available in a week permitted the plant maintenance organizations to survive by practicing reactive maintenance. It was common to run a piece of equipment to failure, and then fix it by some temporary means until it could be repaired or replaced on third shift or the weekend. The maintenance departments learned through experience that reactive maintenance or "fire-fighting" was acceptable and that they should stay out of the way as long as the line was running. It is this custom of reactive maintenance that makes the change to three-crew, two-shift so traumatic, so this is where the improvement process must start.

2.3 Project Description

The organization that I worked for during my internship was the Body-In-White Center. This is part of General Motors' North American Operations (NAO) Manufacturing Center. The Body-In-White Center was created in the early 1990's as part of General Motors' plan to become more centralized. The role of the Body-In-White Center is to develop a common process that all of GM's North American assembly plants can use to assemble automobile bodies. The "Bill of Process" (BOP) is a common blueprint that all the divisions are to migrate towards as they make capital expenditures for future models. The primary goal of this common process is to enable knowledge transfer between the various plants and speed up the pace of process improvements. Leading the divisions toward this vision of common processes is the mission of the Body-In-White Center.

As mentioned in the introduction, the internship project was focused on equipment maintenance in the body shop of an automobile assembly plant. The issue to study was the effects that an extended production schedule has on equipment maintenance. The description of my internship project was:

Determine the required adjustments to the N.A.O. Body-In-White common process system design to allow three-crew, two-shift operation. Recommend a standard Three-crew/Two-shift operation that will best support the maintenance requirements of the NAO common body shop.

- Define the operating schedule and work requirements for both maintenance and production.
- Define banking requirements between subsystems required to maintain consistent throughput.
- Define any system reconfiguration requirements (parallel lines, dual tooling, etc.)

The reason for this project was that GM is starting to use extended production schedules in more of its assembly plants, and there is a concern that this could cause problems with the assembly equipment. The main concern is that equipment maintenance considerations have been neglected when the schedules were developed. Each of the plants running a three-crew, two-shift operation has a different schedule than the others, and none of them have been designed to meet the needs of maintenance. Recognizing this fact, one of the goals of the project was to optimize the production and maintenance schedules with respect to maintenance requirements. The other goal of the project was to determine the required modifications to the common process systems designs. This would involve examining the macro equipment specifications: looking at the value of additional work cells and possible revisions to banks between subsystems in order to maintain consistent system throughput. The idea was that additional capacity would enable preventive maintenance to be performed during scheduled production, rather than restricting it to only be completed during scheduled downtime. The optimized schedule and recommended system modifications would then be added to the NAO Bill of Process as a guideline for all of the plants to consider before implementing an extended production schedule.

Chapter 3: Integrative Approach to the Maintenance Dilemma

The objective of the internship project was to determine how to best support the maintenance requirements of a body shop operating a three-crew, two-shift schedule. As stated in the first chapter, it is essential to balance technology, business processes, and people systems when developing the recommendation. Integration of these three systems will produce the best result, so the structured problem solving methodology will be utilized to ensure an integrated solution.

3.1 Identify the Problem

The first step is to look at the situation objectively—What is the goal of the Body Shop? The body shop's goal should be aligned with that of the company, "To make money now and into the future."[9] The way that the body shop supports this goal is by assembling high quality bodies that it sends to the paint shop. The top priorities of the body shop manager are quality and throughput. There is a daily schedule for the plant to meet and the body shop manager is charged with meeting that schedule while utilizing the fewest resources possible. The manager is evaluated on several criteria, but meeting schedule, quality, and cost targets are three of the most important objectives, and generally in that order.

Where does maintenance fit into the body shop organization? What is the role of maintenance with respect to the goal? Maintenance can make a major contribution toward achieving the body shop's goal. In fact, strong maintenance support is essential to achieving the overall plant goal of making money. According to William Landwehr of A.T. Kearney, the primary goal of a World Class maintenance organization is asset optimization[10] (figure 3.1). This goal is completely congruent with the priorities of the body shop manager. Due to the additional strain that the schedule puts on the equipment, a World Class maintenance organization becomes an essential ingredient for success in a three-crew, two-shift operation.

[9] Goldratt, Eliyahu, and Jeff Fox. *The Goal.* Croton-On-Hudson, NY: North River Press, 1984.
[10] Avery, Susan. "World Class Redefines Role of Maintenance", *Purchasing.* March 18, 1993, p.58.

World Class Maintenance Organization

Goal: Asset Optimization

- Improve Throughput
- Lower Cost
- Improve Quality
- Maintain/Expand Capacity and Capability

Figure 3.1 Goals of World Class Maintenance[11]

The most common complaint about three-crew, two-shift from plant maintenance managers was that there was, "Not enough time to maintain the equipment." Further probing revealed, that there were two separate issues within this statement. First, the two ten-hour shifts meant that the equipment was scheduled to run at least twenty hours per day. This left only four hours each day for maintenance, which was usually cut further when the lines ran overtime. The consensus was that this is not enough time to do the prescribed preventive maintenance. The second issue was that the equipment was scheduled to run six days per week, leaving only one twenty-four hour period each week to complete major repairs or improvement projects. This maintenance window was also violated periodically when production scheduled the line to run service parts. The perceived lack of time was the top complaint of the maintenance managers.

The second most popular complaint from the plants was that the, "equipment was not designed to run this much." Equipment reliability was seen as a major problem in the three-crew environments. The argument was that the equipment ran 50% more each week, so it received more wear and tear. A component that required maintenance every 1000 hours will reach that point in eight weeks in a three-crew, two-shift plant versus twelve weeks in a traditional schedule. Reliability problems had frustrated the plants to the point of requesting automatic back-up equipment, so that they could just by-pass any broken equipment and worry about fixing it during the next maintenance window. Equipment reliability is a major issue to address when contemplating the transition to a three-crew, two-shift operation.

So what was the problem to be solved here? Where should the attention be turned? It was now easy to see why the original project description had focused on the schedule and the equipment. Each of these elements was in direct response to the complaints from the plants. The Body-In-White Center was listening to the customer and responding, but was the project addressing the root of the problem? Developing the perfect schedule or adding equipment will not help the plants if the root cause of the problem is not corrected. In fact, focusing on a technical solution, such as adding equipment or banks, without knowing the root cause could actually exacerbate the problem. In the book *The Fifth Discipline*[12], author Peter Senge describes this type of situation as an example of, "Fixes that fail". This archetype is described as, "A fix, effective in the short term, which has unforeseen long-term consequences which may require even more use of the same fix." The remedy for this type of problem is to maintain focus on the long term. Resist the short term "fix" that merely alleviates the symptoms, and concentrate on addressing the root cause. The ultimate solution for this project must address the root cause of the maintenance dilemma.

To complete this first step, Identify the Problem, a clear theme must be stated. This theme is important because it will become the mission of the problem solving effort. The theme must be stated as a problem rather than a solution. It should focus on a single issue that is important to the customer and it should be stated with a weakness orientation. Considering the objectives of the body shop manager -- throughput, quality, and cost -- it appears that equipment breakdowns would be the most troublesome problem. This hypothesis is supported by the fact that the top two complaints, equipment reliability and lack of maintenance time, are closely related to equipment downtime: Reliability is a possible cause of downtime, and lack of repair time is a likely effect. The major issue to resolve here is equipment downtime; so the theme of this problem solving effort should focus around reducing maintenance related downtime. Downtime in this context can be defined as the total amount of time that a machine is unavailable for productive use due to a breakdown. As figure 3.2 illustrates, the actual repair time is only one component of the total downtime. The total maintenance downtime includes: response time, diagnosis, retrieving spare parts, repair, and validation of the repair. Therefore, the theme of this problem solving effort is: *Reduce total maintenance related downtime to zero.*

---

[11] Avery. (1993)
[12] Senge, Peter. *The Fifth Discipline.* New York: Doubleday, 1990.

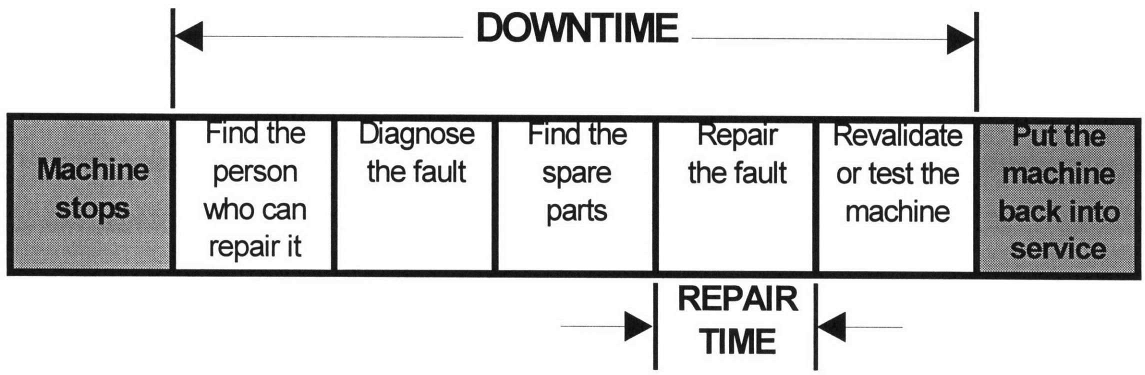

Figure 3.2 Downtime vs. Repair time [13]

3.2 Collect and Analyze the Data

Now that a clear theme has been developed, information must be collected to help solve the problem. The data collection step was an iterative process that involved several visits to various General Motors assembly plants. The observations outlined in this section were made during week-long visits to the Lordstown, Saturn, and Moraine assembly plants.

3.2.1 Lordstown

Lordstown Assembly was the first of General Motors' North American plants to switch to three-crew, two-shift in August of 1992. The Lordstown three-crew, two-shift production schedule is the easiest to understand because the schedules are fixed for each crew. The three production crews that work four, ten-hour shifts each week. The "A" crew works the day shift Monday through Thursday. The "B" crew works the evening shift Tuesday through Friday. The "C" crew, which was added for three-crew, two-shift, works Friday and Saturday on the day shift, and then switches to the evening shift for Sunday and Monday. The twenty-five hour weekend maintenance window started with the Saturday evening shift. The new production week starts with the "C" crew at 7:00p Sunday evening.

[13] Moubray, John. *Reliability Centered Maintenance*. Oxford, England: Butterworth-Heinemann, 1991. p. 64.

Lordstown 3-Crew / 2-Shift Production Schedule

Shifts	Sun	Mon	Tue	Wed	Thu	Fri	Sat
DAYS 6:00A - 4:00P		A	A	A	A	C	C
NIGHTS 5:30P - 3:30A	C	C	B	B	B	B	

Figure 3.3 Lordstown Production Schedule

The maintenance department crews do not follow the production crew schedule. The pipe-fitters, electricians, millwrights, and toolmakers all work a traditional schedule of five eight-hour days on three shifts. Lordstown had started out with dedicated "D" and "E" crews to cover the weekend, but has since gone to voluntary overtime to staff the weekend shifts. There is, however, still a seven person "E" crew to ensure that there are enough electricians for the Sunday evening shift start-up. In the body shop the primary trade is the Welder Electrical Machine Repair (WEMR's). The WEMR's work on a four-crew schedule. "A" & "B" crews work four twelve-hour days, while "D" & "E" work three twelve hour days. ("A"= M-Th Days, "B"= Tu-F Nights, "D"= F-Su Days, "E"= Sa-M Nights). This arrangement was developed by the WEMR's themselves as an alternative to mirroring the production crews. It gives the twenty-four hour coverage that management wanted, while avoiding the shift rotation that the production "C" crew goes through every weekend. With all of the different schedules, there are many combinations of people who need to interface with one another, making communication a significant issue to consider.

Lordstown WEMR Schedule

Shifts	Sun	Mon	Tue	Wed	Thu	Fri	Sat
DAYS 7:00A - 7:00P	D	A	A	A	A	D	D
NIGHTS 7:00P - 7:00A	E	B	B	B	B	E	E

Figure 3.4 Lordstown WEMR Schedule

The maintenance organization at Lordstown is a central resource, covering the entire plant. The other plants all followed some type of area management arrangement. In an area management arrangement, the body shop, paint shop, and general assembly areas all operate as separate business units. The area manager of the body shop directs both production and maintenance within the body shop. At Lordstown, the move to area management had been resisted by the maintenance department, but many assumed that the change was inevitable. The maintenance department had a very traditional hierarchy. The first level of supervision was split up functionally, with a separate supervisors for the pipe-fitters, millwrights, electricians, and WEMR's. Each of these supervisors reported to a general supervisor, who reported to a crew manager. In addition to the three crew managers, a maintenance planner and a small engineering group reported to the maintenance manager.

Lordstown Maintenance Organization

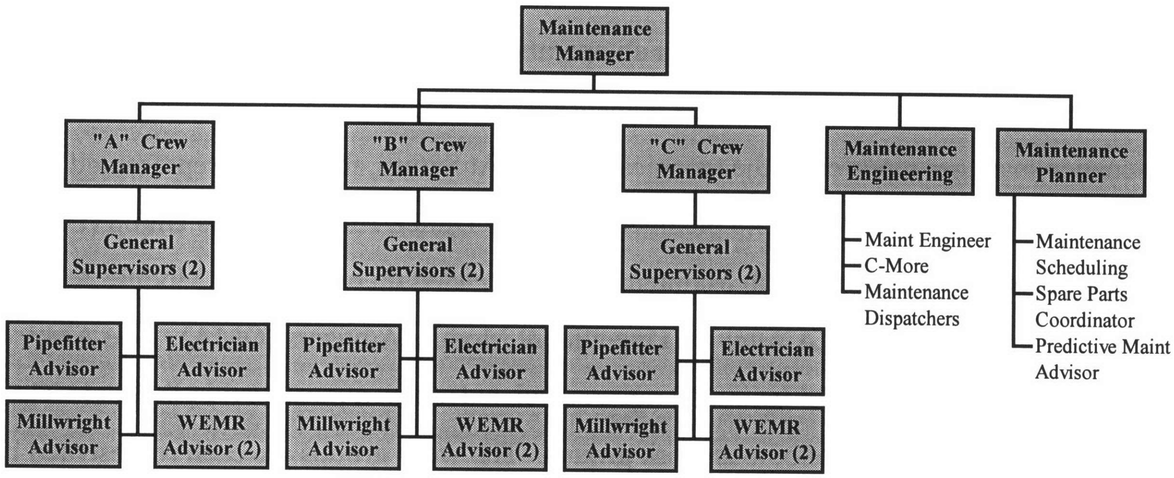

Figure 3.5 Lordstown Maintenance Organization

3.2.2 Saturn

Saturn added their third crew in July of 1993. The Saturn production schedule operates Monday through Saturday. Unlike Lordstown, the Saturn maintenance crews follow the same schedule as the production crews. In addition, at Saturn all three crews rotate between day shift and night shift on a three week cycle. Within a cycle, each crew works six day shifts and six night shifts, and has nine free days. The day shift runs from 6:00a - 4:00p, and night shift goes from 4:30p - 2:30a.

Saturn 3 Crew / 2 Shift Schedule

	WEEK 1							WEEK 2							WEEK 3						
CREW	M	Tu	W	Th	F	Sa	Su	M	Tu	W	Th	F	Sa	Su	M	Tu	W	Th	F	Sa	Su
A			1	1	1	1		1	1			2	2		2	2	2	2			
B	1	1			2	2		2	2	2	2						1	1	1	1	
C	2	2	2	2						1	1	1	1		1	1			2	2	

Shift System: 1 = Early Shift (6:00a - 4:00p
2 = Late Shift (4:30p - 2:30a)

Work Cycle: 12 Working Days / 21 Calendar Days

Figure 3.6 Saturn Production Schedule

As expected, Saturn had a unique organizational structure. Within Saturn Body Systems there were three major areas: Paint, Panels, and Body Fabrication. The Body Fab organization could be called the body shop. The Body Fab operations and maintenance groups each reported to separate organizations. The operations manager reported to the operations group and the maintenance manager reported to the technical group. At Saturn, the terms "represented" or "non-represented" are used to denote membership in the United Auto Workers Union (UAW), rather than hourly and salaried. Fab Maintenance was headed up by the Area Module Advisors (AMA). Reporting to the AMA's are the Operational Module Advisors (OMA). The AMA and OMA positions are each staffed by both a represented and a non-represented individual. The OMA pairs supported the autonomous work groups. The work groups are each represented by a team leader called a Work Unit Coordinator (WUC). The work groups are divided into six separate areas: Underbody, Body Sides, Precision Measurement, Framing, Hang-Ons, and the Central Resource Team. There is also a maintenance planner that reports to the AMA, along with a small group of maintenance engineers. The planner serves as the coordinator for the planners from each of the autonomous work groups.

Saturn Body Fab Maintenance

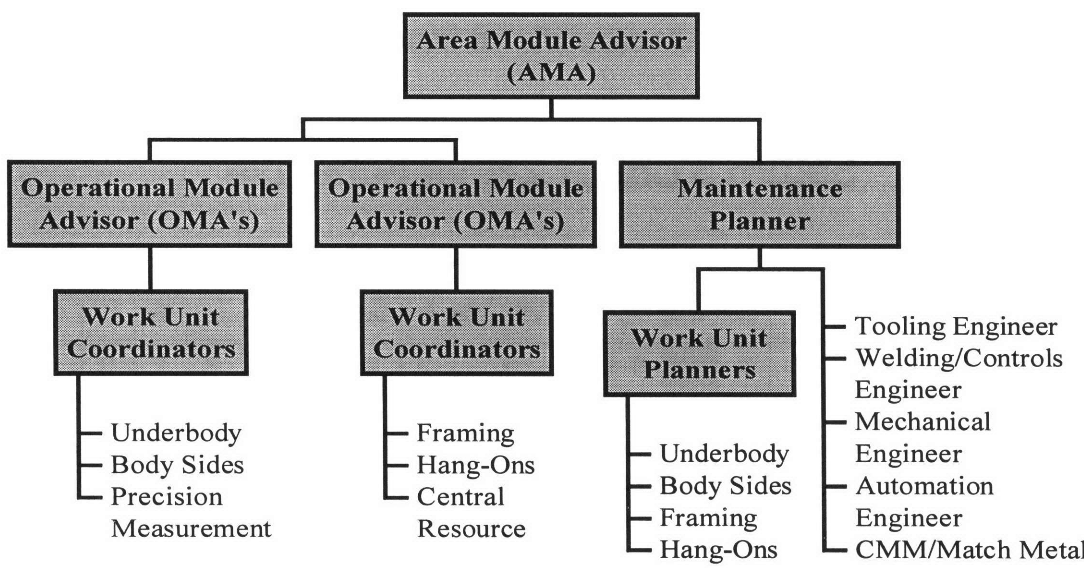

Figure 3.7 Saturn Body-Fab Maintenance Organization

The maintenance window from 2:30a - 6:00a is covered by a skeleton crew of maintenance personnel who work the "window". Working the window shift requires the team member to start later, between 8:00p and midnight, so that their ten hour shift covers the entire between-shift downtime period. Working the window is voluntary, but at least two people per work team are expected to be available. The team members usually rotate who covers the window because there is a pay premium. The window crew is intended to be used for preventive maintenance tasks, but is occasionally assigned to perform equipment repairs left over from the preceding shift. The need for a window crew is one of the disadvantages of having of the maintenance crews following the same schedule as production.

3.2.3 Moraine

The Moraine truck assembly plant introduced three-crew, two-shift in June 1995. The three-crew, two-shift schedule developed by Moraine was different from both of the other schedules. The Moraine schedule covers two weeks, with each crew working eight shifts during the two week period. The "A" crew always works days and the "B" crew works nights. The "C" crew switched between the day and the night shifts. The schedule covered Monday through Saturday with no production on Sunday. Moraine starts their shifts twelve hours apart; day shift 5:18a - 3:48p and night shift 5:18p - 3:48a. The thinking here was that having the two shifts twelve hours apart would simplify things for the "C" crew which switches from nights to days each week. This gives them the same start time, same meeting times and same quitting time; just twelve hours apart. Both production and maintenance followed the same schedule.

Moraine 3-Crew / 2-Shift Schedule

Shifts	Mon	Tue	Wed	Thu	Fri	Sat	Sun	Mon	Tue	Wed	Thu	Fri	Sat	Sun
DAYS 5:18A - 3:48P	A	A	A	A	C	C		C	C	A	A	A	A	
NIGHTS 5:18P - 3:48A	C	C	B	B	B	B		B	B	B	B	C	C	

Figure 3.8 Moraine Production Schedule

Moraine's schedule presents some unique challenges to the maintenance department. The major effect on maintenance is that they are left with two 90 minute maintenance windows, rather than one three hour window. Some supervisors commented that the short window forced them to leave most of the larger preventive maintenance tasks for the weekend. Another issue with this schedule is getting people to cover the maintenance windows. Maintenance is only required to stay thirty minutes past line time to replace weld caps and prepare the line for the next shift. Any other work during the between-shift windows must be covered by voluntary overtime. The short maintenance windows and lack of a dedicated crew to cover between shifts make preventive maintenance planning difficult and usually forces much of the work to be pushed back to Sunday.

The Moraine body shop has taken the concept of the area management all the way down to the first line supervisor. The body shop area manager has five superintendents as direct reports. There is a superintendent for each of the three work crews, one for engineering, and another for tooling and quality. The tooling superintendent is responsible for the toolmakers who handle the precision measurement area, and all body shop tooling issues. The work crew superintendents each have three general supervisors that cover different geographical areas of the body shop. Each of the general supervisors has two supervisors who support both maintenance and production. Within the body shop, most of the maintenance work is handled by the WEMR's. There is also an electrician and a millwright that handle conveyor issues and a pipe-fitter available on-call. The body shop was the first department at Moraine to integrate the production and maintenance organizations.

Moraine Body Shop Organization

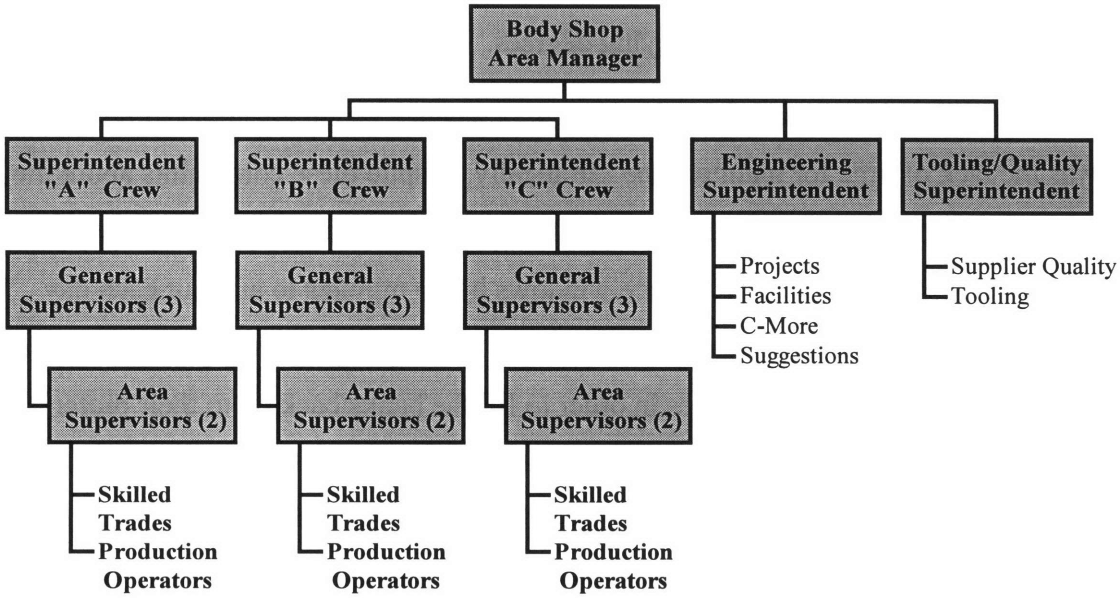

Figure 3.9 Moraine Body Shop Organization

3.2.4 Common Problems

During the visits, it became evident that despite all of the effort that each of the plants was putting into maintenance, they were still battling to keep the lines running. Although they were doing many things to try to cope with the demands of the three-crew, two-shift schedule, every day was a challenge. There was a common frustration of never having enough time to do everything that needed to be done, so they were continually making trade-offs. Could the leaking hose last one more hour until the end of the shift? Can the repair on the clamp cylinder wait until Sunday, so that the weld gun cable can be replaced tonight? The problem was that they had never really changed their basic approach to maintenance. They were still practicing reactive maintenance by letting the equipment breakdowns determine their priorities. This approach was feasible with the traditional schedule, but in a three-crew, two-shift environment, there is no recovery time available to fix breakdowns. To make three-crew, two-shift work, the breakdowns must be avoided. The key is to work smarter, not harder.

The following section outlines some of the general observations that were made during the plant visits. These examples are not meant to single out any one plant because the basic issues were common to all of the plants to varying degrees.

Overtime: The biggest complaint from the maintenance managers about three-crew, two-shift was the lack of time for maintenance. Ironically, despite these complaints about the lack of time, all three plants cut into it further by regularly running overtime. The routine use of overtime usually reduced the maintenance windows by 30 minutes to an hour each day. When asked about the overtime, most managers explained that it was necessary for "line balancing". This generally meant running the lines in order to fill the banks back up to their preferred level so that the following shift would start smoothly. It was common for some of the body shops to run at least 30 minutes of overtime after every shift. When the overtime was coupled with the time it took to change caps on all of the weld guns, almost an hour of the maintenance window was gone. This was particularly troubling at Saturn because they only had half an hour between the day shift and the night shift. The result was that Saturn could only utilize about fifteen minutes of overtime at the end of the day shift for line balancing or making up production losses.

Time Management: With time being such a precious resource, it was surprising to see so much time wasted during the daily maintenance windows. All of the plants did decent jobs of planning the available resources for the weekend, but they did not seem to take advantage of the between-shift windows. When asked about the weekly work schedule, one planner replied that preventive maintenance (PM) tasks were scheduled for the weekend because there was not enough time during the week. The daily windows were commonly used to complete preventive maintenance tasks that had not been finished on Sunday, but PM was generally not assigned during the week. The time between shifts was used to service the equipment and fix any problems that had come up during the previous shift.

Problem Documentation: None of the plants seemed to do a thorough job of documenting and analyzing equipment problems. Although they all had some sort of form that they filled out to explain major breakdowns, the maintenance departments did not utilize the information to solve their problems. Most problems were never even written up because they did not have to be documented unless the equipment had been down for at least twenty minutes. It appeared that the goal for many supervisors was to avoid ever having to fill out the form because it brought a lot of unwanted attention. The sheets were seen as a mechanism to inform plant management about specific incidents that had impacted production, rather than as a tool for improvement.

Some of the supervisors had developed a system for tracking problems in their own area, but there was no common practice. Most problem solving was done on the fly, while the machine was down. If the maintenance person was lucky, they would have encountered the problem before and known how to fix it, otherwise they had to do some quick thinking. When the machine was back up and running, the incident was history. The details of what had broken, and the remedy were usually passed on to the supervisor and some colleagues, but the repair person was not required to follow-up any further. If there was any report to be made, it was usually the supervisor's responsibility.

Reliability and Maintainability: The reliability and maintainability of the equipment was a major issue for the maintenance crews. One of the plants in particular had spent a lot of time streamlining the tools in order to increase reliability. To simplify the equipment, they had removed redundant proximity switches and replaced moving locating pins with stationary pins. They also spent a great deal of time integrating the control logic between stations to improve the system performance. In addition, to improve maintainability they moved several valve packs, I/O boxes, and control panels that had hampered accessibility due to the tight spacing of the tooling. All of the plants agreed that more emphasis needed to be placed on maintainability because, as one electrician put it, "When you only have half an hour to fix something, it can't take ten minutes to get to it." Engineering can make a major impact in this area because the intrinsic reliability and maintainability of the equipment are determined by decisions made during the design stage.

3.3 Determine The Root Causes

In the previous step, information about the problem was collected to give insights into the problem and suggest some of the possible causes. Now, the third step in the problem solving methodology is to determine the suspected root causes of the problem. To facilitate this process, a cause and effect, or fishbone diagram, was constructed. The fishbone diagram gives a visual representation that helps identify the relationships between the possible causes. The root of the problem can then be found by focusing on the causes that the data show to be most influential. Once the root cause is uncovered and understood the process can continue toward determining the most effective solution.

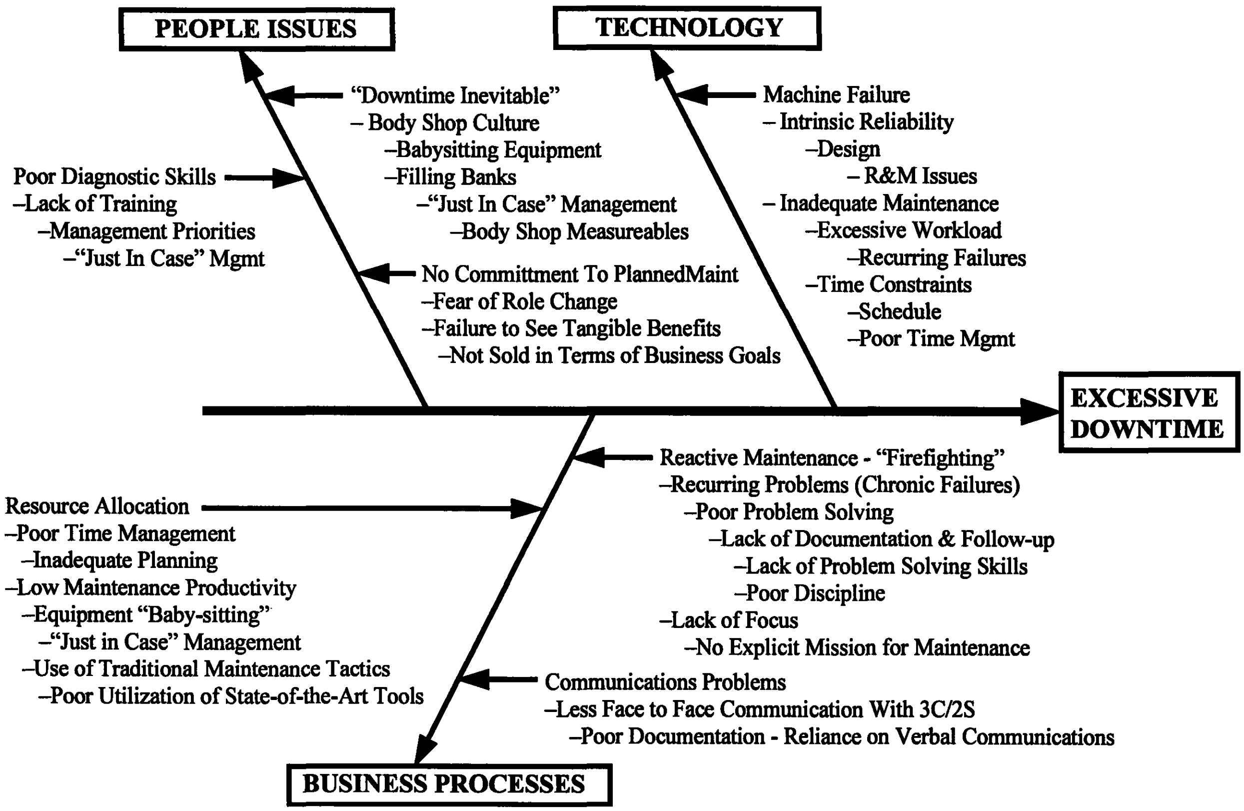

Figure 3.10 Possible Causes of Excessive Downtime

The fishbone diagram for the maintenance problem had the effect of excessive downtime at the head of the diagram. The three categories of causes of this effect were Business Processes, People Issues, and Technology; corresponding directly with the three management systems from the Integration Framework. Within each of these categories are then several layers of possible causes of excessive downtime, with each successive layer being the suspected cause of the previous problem. The root causes of the excessive downtime are usually found deep within these layers. The fishbone diagram effectively mapped out the suspected causes, and helped reveal the interdependence of the three systems.

3.3.1 Business Processes

Reactive Maintenance: The most obvious contributor to excessive downtime within the category of Business Processes is the practice of reactive maintenance. Reactive maintenance, commonly referred to as "fire-fighting," reinforces the notion that there is never enough time to do things the right way. By letting the equipment breakdowns determine their priorities, the maintenance organization was not able to manage its resources control efficiently.

The mechanism that traps an organization in this reactive mode is chronic failure. The reason for the perceived lack of time is that maintenance resources are tied up fixing the same problems over and over. It is not the two-hour breakdown that occurs every four months that causes daily overtime, it is the two minute stoppage that happens ten times per day. The small recurring failures are the real problem.

The root cause of these chronic failures is poor problem solving. Typically, when a machine fails the maintenance person responsible for the area responds quickly to diagnose the failure and repair the equipment. After the line is running again, the maintenance person usually just returns to his or her post to wait for the next breakdown. As long as the repair was not just a quick fix to get through until break, the episode is usually complete. There is usually very little documentation or follow-up of the equipment failure. The main problem with this practice is that the knowledge gained during the failure diagnosis and repair can only benefit the person or group that participated. Without some form of documentation, the rest of the organization will not benefit from the learning. In addition, the lack of follow-up reinforces the reactive maintenance cycle because the problem will probably return since it is unlikely that the root cause was eliminated.

In most of the plants, the only problems that required documentation and follow-up were safety problems and any breakdowns that resulted in a line stoppage of twenty minutes or more. The plants all had some type of problem log sheet to be filled out by the supervisor, but they served little use in eliminating downtime. The downtime log sheets were not very useful for eliminating chronic failures because they did not request enough detailed information. The sheets asked for a description of the problem, the suspected root cause, and whether any follow up was required; but the level of detail was left to the discretion of the individual supervisor or trades person. The poor documentation of equipment failures inhibited successful problem solving.

It was also evident from the sheets that problem solving skills in general needed some improvement. In many cases, the response for the root cause was just an explanation of the remedy that was used to get the equipment running again. There was no indication that a systematic analysis process was utilized to determine the actual root cause. Overall, there seemed to be lack of discipline throughout the whole organization with regard to documenting and following up routine equipment failures. This allowed the chronic problems to linger and consume maintenance resources.

The other contributor to the practice of reactive maintenance was a general lack of focus within the maintenance organization. In most of the plants the maintenance department had no explicit mission. When asked, most maintenance personnel replied that their job is to keep the body shop running. There was no goal of continuous improvement, or zero defects; just to maintain the status quo. The lack of focus supports the habit of reactive maintenance.

Resource Allocation: Poor allocation of resources was another possible cause of excessive downtime. Due to its scarcity, time was the most important of these resources. Time was squandered every day in the body shop due to poor time management. Many hours of scheduled downtime were routinely wasted each week due to inadequate planning of maintenance projects and tasks. The failure to schedule work for the between-shift windows by itself resulted in a tremendous waste of scheduled maintenance downtime every day. Low maintenance productivity was another source of waste. Depending on traditional maintenance tactics rather than adopting state-of-the-art maintenance tools reduces maintenance productivity and intensifies the time constraints that lead to equipment downtime.

Communication Problems: The third contributor to downtime from this category was poor communication. Because of the different schedules, there is less of an opportunity for face to face communication in the three-crew, two-shift environment. Maintenance has traditionally relied on this type of verbal communication to inform colleagues about the day's events and problems. Clear written documentation becomes more important in the absence of face to face contact. Without an effective communication system, problems can fall through the cracks and result in downtime.

3.3.2 People Issues

Within this category of causes are all the people and cultural issues that contribute to the ultimate effect of excessive downtime. These issues are usually the most difficult to identify and attack because they are hard to recognize from within the organization. Often it requires the perspective an objective outsider to point out the source of chronic problems. Without this perspective it is difficult for the organization to acknowledge that their "system" could actually be the cause of many of its own problems.

"Downtime Inevitable": The most prominent problem in this category was the apparent acceptance of equipment downtime as an inevitable fact of life. The belief that downtime was unavoidable seemed to be ingrained in the entire body shop culture. This fear of imminent equipment failure manifested itself in large banks of finished parts between subsystems that could feed downstream processes for several minutes, or even hours. Each of the plants routinely ran overtime to keep these banks filled. In addition, the most critical equipment usually had a dedicated trades person stationed nearby to jump into action and repair the machine if it failed. These "Just in Case" management tactics cause excessive downtime by fostering a "fire-fighting" environment. The practice of reactive maintenance only reinforces the belief that equipment downtime is inevitable and sustains the cycle.

No Commitment to Planned Maintenance: The second problem within this category was the perceived lack of commitment toward implementing planned maintenance. General Motors has its own GM-UAW version of Total Productive Maintenance (TPM) called the Quality Network Planned Maintenance program (QNPM). Despite the fact that GM CEO Jack Smith, and UAW President Steve Yokich had both publicly proclaimed the importance of Planned Maintenance, there was no sense of urgency apparent on the shop floor. Ironically, two of the plants who could benefit the most from a structured proactive maintenance program, Lordstown and Moraine, seemed to be among the slowest to implement QNPM. One explanation for their hesitation to implement the system could be fear of changing roles or losing status. In the current system, when the line goes down and maintenance arrives they are heroes who have shown up to restore order. In the proactive maintenance environment promoted by QNPM, the maintenance department works behind the scenes, keeping the line operating smoothly. If the line does go down, they are held accountable for not doing their job rather than applauded for saving the day. Another reason could be that management just does not see the tangible benefits. Implementing this type of program takes a great deal of time and a strong commitment from plant management. If the program was not sold to plant management in terms of their business goals it is unlikely that the program will get the support that it needs to succeed. The lack of a strong proactive maintenance program directly contributes to the problem of excessive downtime.

Poor Diagnostic Skills: The third possible cause of downtime in this category is poor diagnostic skills within the maintenance department. This skill deficit can be a result of insufficient training in the latest technologies or the skill atrophy that can occur when trades people are allowed to rely on their coworkers to do most of the work. These situations can occur when the organization focuses too much on short term priorities. Excessive downtime can be a direct result of inadequate technical skills.

3.3.3 Technology Issues

Equipment Failure: The main issue within this category is equipment failure. The two basic causes of machine failure are its intrinsic reliability and inadequate maintenance. A machine's reliability is determined by its design and construction. Maintenance cannot yield reliability beyond this inherent level. Failure to consider reliability and maintainability issues in the design stage can cause excessive machine failures due to poor reliability. The other major cause of equipment failure is inadequate maintenance. Poor maintenance is the result of time constraints or an excessive workload due to recurring failures. The time constraints are caused by a combination of the three-crew, two-shift schedule and poor time management. An excessive workload is another effect of recurring failures. Equipment failure is the most direct contributor to the problem of excessive downtime.

3.3.4 Root Causes

The final task in this step is to determine which of the causes on the fishbone can be singled out as the root cause of the main effect. Looking at the fishbone diagram, it is easy to see the interdependency of the three main categories. Several of the issues show up as causes in more than one category. To find the root cause, we must focus on the cause that the data shows to be the most influential. Among all of the possible causes, equipment failure appears to be the most substantial contributor to the problem of excessive downtime. Therefore, to eliminate the problem of excessive downtime we must reduce equipment failure. To do this, we must resolve two basic issues: first, machine failures due to inadequate maintenance; and second, machine failures due to intrinsic reliability.

3.4 Develop Integrative Solution

Now that the suspected root causes have been determined, a solution can be developed. The intent of this step is to develop an integrative solution that balances the needs of all three management systems—people, business, and technology. Ideally, the solution should reverse the effects of the root cause and eliminate the problem. The solution will need to address the issues of inadequate equipment maintenance and intrinsic equipment reliability; so its major elements should include proactive maintenance and reliability. In addition, besides solving the problem, the solution must also support the business goals of the organization if it is to add value to the company.

3.4.1 Total Productive Maintenance [14]

Total Productive Maintenance (TPM) is the integrative solution that is needed to address the problem of excessive downtime. TPM is a company-wide equipment maintenance system developed in Japan during the 1970's to support sophisticated production facilities. TPM was designed around two main objectives: zero breakdowns and zero defects. The term TPM was

[14] Much of the information on TPM in this section is derived from the writings of Seiichi Nakajima – *Introduction to TPM* and *TPM Development Program*, published by Productivity Press.

defined in 1971 by the Japan Institute of Plant Engineers (now the Japan Institute for Plant Maintenance) to include the following five goals:

1. Maximize equipment effectiveness (improve overall efficiency).
2. Develop a system of productive maintenance for the life of the equipment.
3. Involve all departments that plan, design, use, or maintain equipment in implementing TPM (engineering and design, production, and maintenance).
4. Actively involve all employees—from top management to shop-floor workers.
5. Promote TPM through motivation management: autonomous small group activities.

TPM is not just a maintenance program. To be successful a TPM program must have involvement from every organization in the plant. TPM is actually a production driven improvement methodology, designed to optimize equipment reliability and ensure efficient management of plant assets. Japan's Seiichi Nakajima, the father of TPM, describes TPM as, "Productive maintenance carried out by all employees through small group activities." The word "Total" in Total Productive Maintenance has three distinct meanings relating to three important features of TPM:

1. ***Total effectiveness:*** pursuit of economic efficiency and profitability.
2. ***Total participation:*** autonomous maintenance by operators and small group activities in every department and at every level.
3. ***Total maintenance system:*** establishing a maintenance plan for the entire life of equipment that includes maintenance prevention and activity to improve maintainability as well as preventive maintenance.

As factories become more automated, production is shifting from the hands of the workers to the machinery. Equipment and machinery are becoming critical factors for increasing output. Output—productivity, quality, costs, delivery, safety and morale—is significantly influenced by equipment conditions. The goal of TPM is to enhance equipment effectiveness and maximize equipment output. In addition, it seeks to enhance the overall efficiency, including economic efficiency, by minimizing the cost of upkeep and maintaining optimal equipment conditions throughout the life of the equipment. Equipment effectiveness can be described as a measure of the value added to production through equipment. TPM seeks to maximize equipment effectiveness and minimize total costs through elimination of the following "six big losses":

Downtime:

1. *Breakdown Losses:* These can be divided into two types: sporadic and chronic. Sporadic breakdowns – sudden, dramatic, or unexpected equipment failures – are obvious and usually easy to correct because their causes are relatively simple to trace. On the other hand, chronic breakdowns – frequent minor failures – tend to linger because they are often ignored or neglected after several unsuccessful attempts to cure them. Chronic problems tend to resist traditional remedies because their roots are usually hidden in the structure of the equipment or the methods of the organization.
2. *Set-up and Adjustment:* Losses from set-up and adjustment result from downtime and defective products that occur when the equipment is set up for a new product or adjusted back to a design nominal condition. Set-up and adjustment time can be reduced significantly by making a clear distinction between *internal* set-up (must be performed while machine is down) and *external* set-up (can be performed while the machine is still running), and by reducing internal set-up time.[15]

Speed losses:

3. *Idling and Minor Stoppages:* A minor stoppage occurs when production is interrupted by a temporary malfunction or when a machine is idling. For example, a work-piece might get stuck on a locating pin during ejection causing the machine to idle, or light screen or safety mat could be activated, shutting down the equipment. These types of temporary stoppage clearly differ from a breakdown, but often require the intervention of maintenance personnel. Normal production is usually restored by simply removing the obstructing work-piece and resetting the equipment.
4. *Reduced Speed:* Reduced speed losses refer to the differences between equipment design speed and actual operating speed. Speed losses are typically overlooked in equipment operation, although they can contribute significantly to productivity losses.

Defects:

5. *Quality Defects & Rework:* Quality defects in process and rework are losses in quality caused by malfunctions in production equipment. Like breakdowns, they can be classified as sporadic or chronic. Sporadic defects are conspicuous because they are considerably different than the status quo, while chronic defects tend to be overlooked and remain hidden because they are difficult to quantify.
6. *Start-up Losses:* Reduced yield between machine startup and stable production. Similar to the case of chronic failures, the possibility of eliminating start-up losses is often obscured by the uncritical acceptance of their inevitability.

---

[15] For a thorough treatment of the subject of reducing set-up times see: Shigeo Shingo, A Revolution in Manufacturing: The SMED System. Cambridge, MA: Productivity Press, 1985.

TPM's focus on the six big losses is closely tied to the absolute elimination of waste advocated by the Toyota Production System. Total Productive Maintenance provides essential support for the Toyota Production System. TPM is a necessary to provide the equipment effectiveness required to successfully operate in a Just in Time production environment. Figure 3.3 illustrates how TPM's six big losses correspond to the primary elements of the Toyota Production System and it's quest for the absolute elimination of waste.

TPS \ TPM	Breakdowns	Set-up & Adjustment	Idling & Minor Stops	Reduced Speed	Quality Defects	Reduced Yield
Implementing Flow Process	●					
Eliminating Defects					●	●
Stockless Production	●	●				
Reduced Lot Size		●				
Quick Set-up		●				
Standard Cycle Times	●	●	●	●	●	
Std Prod'n Sequence	●	●	●	●	●	
Standard Idle Time	●	●	●	●	●	
Visual Control Andon Alarm	●	●	●			
Improved Mach Operability	●	●				
Improved Mach Maintainability	●					

Figure 3.11 Toyota Production System and TPM [16]

In summary, Total Productive Maintenance can be described as a partnership among all organizations within the plant, particularly between production and maintenance. The objective of this partnership is continuous improvement of operational efficiency, product quality, capacity assurance, and safety. TPM supports all the business goals of the body shop—schedule, quality, cost, safety, and morale. It also addresses the problem of excessive downtime directly by focusing on equipment reliability improvement and proactive maintenance practices. Therefore, the implementation of a Total Productive Maintenance program would be a good integrative solution for the three-crew, two-shift maintenance problem.

3.4.2 Quality Network Planned Maintenance

Quality Network Planned Maintenance (QNPM) is the GM-UAW version of TPM. Quality Network Planned Maintenance is described as: "A total systems approach to maintenance involving all employees to increase throughput and uptime, improve quality of output, reduce maintenance costs, and improve safety by continuously improving equipment operation."[17] It is a comprehensive planned maintenance system that includes preventive and predictive scheduled maintenance programs as well as strategies for responding to machinery and equipment failures.

QNPM is a very thorough program that is essentially the same the TPM program outlined by the Japan Institute for Plant Maintenance (JIPM). The basic difference between QNPM and TPM is found in some of the language concerning the role of production operators. Within QNPM the production operators are encouraged to become involved, but their role is more limited than what is permitted in a Japanese plant. The production worker's role is referred to as "Owner-Operator", where the operator of the machine assumes the role of the owner, with responsibilities for the condition of the machinery and equipment. This is analogous to a car owner who is responsible for the upkeep of his car, but generally takes it to the garage for service. The manner in which Owner-Operator is implemented varies between plants, but as a minimum, operators are responsible to see that their equipment is cleaned and that maintenance inspections are performed. The Owner-Operator concept recognizes that the operator has valuable knowledge to contribute about the equipment that they use, and by using his or her senses (eyes, ears, nose), can identify unusual conditions before they become problems.

---

[16] Nakajima, Seiichi. *TPM Development Program: Implementing Total Productive Maintenance*. Cambridge MA: Productivity Press, 1989.

[17] Weekley, Thomas L., and Jay C. Wilbur. *United We Stand: The Unprecedented Story of the GM-UAW Quality Partnership*. New York: McGraw-Hill, 1996

Top management at General Motors and the leaders of the UAW have stated that they believe the Planned Maintenance Action Strategy is essential to improving GM's overall manufacturing competitiveness. They have shown their commitment to the process by establishing a central resource to coordinate and lead the implementation process. The NAO-Planned Maintenance Implementation (PMI) Team is a GM-UAW jointly staffed organization, headquartered at the General Motors Tech Center in Warren, Michigan. Their mission is to promote the Quality Network Planned Maintenance Action Strategy and assist in its implementation across all of General Motors' North American Operations. The organization is divided into several teams, each responsible for a set of plants in a geographical region. The teams are responsible for helping the plants implement the program by providing technical assistance and tools, in-plant needs analysis, and training. The PMI teams work on a pull-system basis; they are available as a resource, but they do not try to force their services on the plants. To enjoy long term success, it is up to the plants to commit to the process.

Although implementation in some of the assembly plants has been relatively slow, several of the components plants have fully implemented the process and have seen dramatic results. The Quality Network publishes a quarterly newsletter called "Knowledge Transfer" in which it documents some of the accomplishments that the plants have attributed to QNPM. Many plants have reported decreases in maintenance related downtime, major savings from spare parts reduction, an increase in employee training, and substantial reductions in overall maintenance costs. In addition, the implementation of Planned Maintenance has yielded people benefits also in the form of higher morale and lower absenteeism.[18] The plants that have committed to QNPM are receiving the benefits that QNPM promises.

The aim of QNPM is to develop a partnership between maintenance and production and union and management that will lead to World Class performance levels. The transformation process will take a lot of hard work and strong management commitment, but the potential rewards will return the investment many times over. Fully implemented, Planned Maintenance will make a significant contribution towards improving safety, quality, uptime and cost.

---

[18] Weekley and Wilbur, (1996).

3.4.3 Antwerp's Transition to Planned Maintenance

The following section provides a case study of the implementation of planned maintenance in the Body Unit of the Opel assembly plant in Antwerp, Belgium. Over a six year period, the Antwerp Body Unit underwent a transformation from a struggling organization which could barely keep up with its production requirements to a World Class body shop focused on safety, quality, cost, productivity and people. This dramatic transformation was the result of the implementation of Planned Maintenance. The purpose of this case study is to illustrate the value of proactive maintenance in a three-crew, two-shift environment.

Three-crew/Two-shift: Antwerp started running the new three-crew, two-shift schedule in August of 1988. Due to Belgian labor laws and cultural differences, there are several differences in the way that the Antwerp schedule is structured when compared to those in the US. The first difference is that there are only eleven shifts or 110 hours of production per week in Antwerp versus 120 hours in North America. This is due to the strict labor laws that limit the work week. Their weekly schedule starts at 5:30a on Monday, and ends at 3:30p on Saturday. Antwerp does not run production on Saturday evening because that is the Belgian social night. It is customary that Saturday evening is set aside to socialize with family and friends. Another result of the limited work week is that almost no overtime is allowed. If a worker works overtime he or she is entitled to overtime pay plus additional time off, so it is not feasible for factories to work overtime. Another distinction of the Antwerp schedule is that all crews rotate between day and night shift on a three week cycle. Rotation is common for shift workers in Belgium; it is done to ensure fairness among the crews.

The maintenance crews do not follow the production crew schedule. The maintenance crews follow a traditional schedule of five eight-hour days on three shifts. Maintenance crews also rotate shifts weekly, from nights to late to early on a three week cycle. To cover the weekend, there are two dedicated crews that each work two twelve-hour shifts per week. The weekend crew is an attractive assignment; they only work 24 hours per week, but due to the weekend premiums they get the same amount of pay as the regular crews. The weekend crews also rotate from days to nights. Since overtime is never used for production, the early and late production shifts butt together. This eliminates the break between shifts to change weld caps or quick repairs, but it gives maintenance a four hour window to perform preventive maintenance work each night.

3 Crew / 2 Shift Production Schedule

	WEEK 1							WEEK 2							WEEK 3						
CREW	M	Tu	W	Th	F	Sa	Su	M	Tu	W	Th	F	Sa	Su	M	Tu	W	Th	F	Sa	Su
A	1	1	1	1				2	2			1	1				2	2	2		
B			2	2	2			1	1	1	1				2	2			1	1	
C	2	2			1	1					2	2	2		1	1	1	1			

Shift System: 1 = Early Shift (5:30a - 3:30p)
2 = Late Shift (3:30p - 1:30a)

Work Cycle: 11 Working Days / 21 Calendar Days

Figure 3.12 Antwerp's 3-Crew/2-Shift Production Schedule

3 Crew / 2 Shift Maintenance Schedule

	WEEK 1							WEEK 2							WEEK 3						
CREW	M	Tu	W	Th	F	Sa	Su	M	Tu	W	Th	F	Sa	Su	M	Tu	W	Th	F	Sa	Su
A	1	1	1	1	1			3	3	3	3	3			2	2	2	2	2		
B	2	2	2	2	2			1	1	1	1	1			3	3	3	3	3		
C	3	3	3	3	3			2	2	2	2	2			1	1	1	1	1		
D						4	4						5	5						4	4
E						5	5						4	4						5	5

Shift System: 1 = Early Shift........ Monday: (5:30a - 2:30p)
Tue - Fri: (6:30a - 2:30p)
2 = Late Shift......... Mon - Fri: (2:30p - 10:30p)
3 = Night Shift........ Mon - Fri: (10:30p - 6:30a)
4 = Early Weekend Shift... Sat: (6:30a - 6:30p)
Sun: (6:00a - 6:00p)
5 = Late Weekend Shift.... Sat: (6:15p - 6:15a)
Sun: (5:45p - 5:45a)

Figure 3.13 Antwerp's 3-Crew/2-Shift Maintenance Schedule

Background: The Opel plant in Antwerp Belgium is where three-crew, two-shift started. The revolutionary new shift system was created out of necessity to facilitate the consolidation of two plants. The three-crew, two-shift schedule was chosen because it preserved the jobs of the older plant's workers while boosting the capacity of the newer plant to the same level as the previous combined total. The move cut total operational costs 20% and raised Plant #2's capacity utilization by 44%. Within months, Plant #2 started setting production records, knocking out 80 cars an hour from a facility rated at 76 jobs per hour.

Despite the boom times, things were not going well in the body shop. The atmosphere was almost chaotic, as the body shop struggled to keep up with their production quota. The new production schedule was taking a toll on the machines and the people. The robots and the equipment were continually breaking down causing quality problems and production delays. The breakdowns turned the focus completely toward attaining the production volumes that compounded their problems even further. During this period the body shop was referred to as the "coal mine" because it was so dark and dirty. Morale was at an all time low. One manager told a story about the day that a young maintenance mechanic had cried on his shoulder and quit because he could not stand to work another day in such a depressing place. The body shop was in bad shape.

In 1989, the plant reorganized into three main sub-units—Body, Paint and Assembly. The new Body Unit manager was a man named Jos Nys. Jos had worked in the two Antwerp plants his entire career, starting out in general maintenance at Plant #1 almost 30 years ago. During his career he had worked his way up through the ranks, starting as a maintenance mechanic. Since 1985 he had been managing the Body Components area as part of a pilot program in area management. As the area manager Jos had controlled production, maintenance, and material within the Components area. When the area management was spread throughout the plant in the summer of 1989, Jos was chosen to lead the new Body Unit. This new unit would consist of the Components Area and the Body Shop.

The Transition: As manager of the Body Unit, Jos Nys' first priority was improvement of the workplace. A program to systematically improve the lighting within the production areas was started. The basic philosophy being, that defects are easier to detect in a well-lit environment. The next step was to start a general cleaning program. Time was set aside daily for tool cleaning. An outside contractor was also hired to do some of the heavier cleaning during the night shift. Everyone was asked to pay attention to cleanliness and order. The 5-S[19] campaign improved morale and helped instill discipline within the entire organization.

By the Spring of 1991, the Body Unit was ready to proceed to the next step in its transformation process. Although housekeeping was still a priority, the focus now shifted toward the elimination of "fire-fighting". As a first step, the maintenance mechanics were told to document every minute of downtime in their area. At the end of each shift, totals for each line, as well as the top reasons were recorded. The performance of each line was tracked weekly and displayed in the Body Unit office as well as the floor. The information quickly pointed out which tools had the poorest reliability and helped focus improvement efforts. Within a few months the downtime records provided enough information to develop a cost/benefit analysis that justified the replacement of all 164 Cincinnati Millicron robots with newer, more reliable Fanuc robots.

Another benefit of the downtime records was a more acute sense of time. The log books showed how all the small problems accumulated to a large amount of downtime. This lead to the third initiative: elimination of wasted time. This was important because time is a precious resource in a three-crew, two-shift environment. The downtime logs illustrated how inefficient work practices were unnecessarily contributing to the total amount of downtime. In response, the maintenance department created something that they called "shadow boards" to reduce the time wasted during a breakdown while looking for parts. These boards were used to stock many of the most common spare parts directly adjacent to the line. It was called a shadow board because it was literally a large board with a painted silhouette of each of the parts affixed to it. The shadows were a means of visual control; the maintenance person could quickly tell where the part should be or where to put a replacement.

By 1991, the Body Unit had reached a turning point. The first two years had required a lot of hard work and perseverance, but it was starting to pay off. The clean-up campaign was instilling

[19] See Appendix A for a brief explanation of 5-S principles.

discipline in the whole workforce, and the initiatives to document downtime and eliminate wasted time had begun to free-up time and reduce costs.

In 1992, an external consultant was brought in to teach the principles of TPM. The initiatives of the past two years had helped start the process. TPM champions were chosen and given the assignment to organize a roll-out plan for the entire Body Unit. In December 1992, four areas were chosen to pilot the TPM process: one area on each of the A, B, and C crews, and one automatic tool. After the team leaders had all been trained in the basics of TPM they were brought together to decide how to best split up the work between maintenance and production. They had to decide what to do, how frequently to do it, and who would be responsible: maintenance or production. TPM was given a new name by Jos Nys: "Teamwork between Production and Maintenance".

In October of 1993, Jos showed his commitment by authorizing time to perform TPM each shift. This was possible due to slow sales that had cut back the production quota. Rather than slowing the line to the new production rate, the line was run at normal speed and a 15 minute TPM break was scheduled each shift. The structured TPM time was scheduled at the beginning of the shift so that the workers could benefit from their own work. The TPM time was so successful that even after the production rate picked back up most areas still found time to complete their TPM tasks. Through the TPM activities, the teams had increased productivity by reducing equipment breakdowns. This made it possible to keep up with the production schedule and still make time for short TPM breaks. The teams were seeing concrete results from their TPM efforts.

During this period the maintenance personnel were used to train the production operators. The operators were taught how to clean and do routine inspections of weld guns, cables, hoses and switches. The training was not only on how to do the tasks, but more importantly, how to do them safely. In some of the areas, the operators had progressed to the point of changing weld caps and tightening loose fittings, but most contributed by cleaning and inspecting.

The idea of training production workers to do their job was initially met with resistance from the maintenance mechanics. The resistance was mainly based on the pride of the mechanics in their trade and fear that TPM would blur the boundaries between the skilled mechanics and a normal production worker. The potential loss of overtime was not an issue as it would be in the US because overtime is not used. Management appealed to the mechanics' pride to reduce the resistance by explaining their motives. The intent of having the operators participate in routine tasks of cleaning and inspection was to free up time for the maintenance mechanics to work on bigger problems. Maintenance mechanics had technical educations that needed to be used to solve technical problems. Instead of being handy-men, they needed to become technical specialists. Maintenance personnel needed to understand that their role was not to fix problems, it was to eliminate them.

The focus of the maintenance problem had now turned to problem solving. The goal was to become proactive by eliminating problems rather than just fixing them. To facilitate the problem solving process, all maintenance personnel were trained in structured problem solving. The training classes were taught over a six week period; one two-hour session with homework assigned each week. Each session covered a single topic or step in the process. The homework was to apply the week's lesson to a problem in your own area. The classes were successful because the single point lessons gave them a chance to absorb the material rather than overwhelming them with information. In addition, the homework assignments helped reinforce the process by giving them a chance to practice what they learned. The problem solving focus has made the Body Unit more proactive and almost eliminated "fire-fighting".

Results: The Opel Belgium Body Unit has come a long way since the "coal mine" days back in 1989. In 1997, the body shop is considered to be one of the best in the world: Average throughput is 83 jobs/hr., equipment uptime is between 95 - 99%, and near perfect quality. Today, the entire Body Unit organization is focused on five priorities: Safety, Quality, Cost, Productivity, and Human Resources. The five priorities are the criteria used to measure performance within the plant. A cross-functional work group, headed by one of the Body Unit managers, was formed to support each priority. The work groups monitor the Body Unit's performance, and develop and implement action plans for improvement.

The transformation process took about six years of hard work, but they are seeing the benefits of Planned Maintenance. The Body Unit is currently undergoing a major expansion to prepare for a new product for 1998. For the new program a lot of work that had been done at other plants has been brought inside for Antwerp to do for itself. This is a sign that Opel's management recognizes the improvements that Antwerp has made. The Antwerp Body Unit now realizes that even though they have come a long way, the journey will never be complete because there will always be the need for continuous improvement.

3.5 Implement Solution

As suggested in the preceding section, the best solution to the three-crew, two-shift maintenance dilemma is to focus on implementing Total Productive Maintenance. For the GM plants this means making a strong commitment to implementing Quality Network Planned Maintenance. QNPM's systematic focus on transitioning to proactive maintenance will reduce the current downtime problem by directly attacking its root causes: reactive maintenance and poor machine reliability.

This recommendation may not be the answer that many of the plant people want to hear. Most of these people will be looking for the magic bullet that will save them from the mythical beast known as three-crew, two-shift. Their previous requests indicate that they are looking for a technical answer to their maintenance dilemma. QNPM recognizes the importance of technical tools, but focuses on the business processes and people issues. The slow pace of QNPM implementation thus far suggests that many people do not recognize the benefits of the system, so the challenge is to make the benefits more tangible to the body shop managers.

3.5.1 Resistance to Implementation

The first reaction of many plant insiders will be to defend the system from the outside attacks by explaining that the outsider, "does not understand" the situation. This defense of the current system is natural, because the insiders have created the system, so any attack on the system can be seen as an attack on them. The only way to promote change in this type of environment is to convince an insider to challenge the system. If an influential insider can take an objective look at the situation and see that things do not make sense, then the system can be changed from within.

To change the system from within there will have to be a culture change. Reactive maintenance has become part of the maintenance culture at General Motors. Planned

Maintenance directly attacks this aspect of the culture, so resistance to implementation can be expected. The resistance comes from fear of the unknown. In this case the fear could be from the fear of a role or status change, the possible loss of overtime, or even the loss of job security.

Fear of a role change is to be expected, because the role of maintenance within a planned maintenance system is different. Traditionally, maintenance people have been rewarded for putting out fires. When there was an equipment breakdown the skilled trades person was called to come fix the problem. Recognition was given to the people who could fix a wide variety of problems quickly. In the environment promoted by the Planned Maintenance system, the skilled trades are expected to work in the background, to make sure that the machine never breaks. If they are called to a breakdown they are more likely to be questioned and held accountable than praised for fixing the machine.

The fear of lost overtime is a very powerful source of resistance. During the plant visits, it became evident that this is a very important issue to address. From conversations with skilled trades people it was obvious that most of them saw planned maintenance as a threat to their overtime. This is a big deal because overtime was seen as a right to some of the skilled trades people. Several admitted that the availability of overtime was a prime motivator for entering the trades. The allure of overtime is easy to understand when you consider that the average skilled trades person can make an extra $1,000 a month just by working one extra shift per week. Over the course of a year, many can make an extra $20,000 - $30,000 from overtime, and many have been working overtime for years. When you have become accustomed to this kind of money, it is unlikely that you would want to give it up. The message is that if planned maintenance is seen as a threat to overtime, as many say it is, there will be a strong resistance to its implementation from the skilled trades.

The third source of resistance comes from a perceived threat to job security. This comes from a blurring of the traditional lines of demarcation that is promoted by TPM through the involvement of production operators in maintenance tasks. The QNPM system does expand the operator's role as much as Japanese would advocate, but many maintenance people feel threatened by the role change. It is human nature to take pride in what one does and to think that you have special qualifications that make you irreplaceable, so it is reasonable to expect some resistance from the skilled trades. The "you operate – I fix" division of labor in America has contributed by reinforcing the idea that the maintenance people are the only ones qualified to work on the equipment. The challenge here is to convince the skilled trades person that they should be worrying about the technical side of maintenance and that simple tasks like cleaning, checking gauges , and changing weld caps do not require their expertise. The production operators can help them and free up their time for more important work. As one of the managers in Antwerp asserted, "if they (production operators) can maintain their own car or house, surely they can clean their own machine."

3.5.2 Overcoming the Resistance

Besides the sources of resistance listed above, there is another barrier to implementation: organizational inertia. This is the force within the organization that tries to keep things as they have always been. To overcome this organizational inertia it will take a strong commitment from the top management of the company. Making a speech about the importance of Planned Maintenance is a good start, but it is a major change so the commitment must go much further. To advance the change, the middle managers -- Superintendents, Area Managers, and even Plant Managers – must be given a clear message that Planned Maintenance is a top priority. They need to be confident that their bosses understand the magnitude of the change being requested, and that their actions will be supported. Everyone must be patient and take a long term perspective.

At the plant level, the managers need to send a clear message to the workforce that things will be done differently from this point forward. One way to send this message is to revise the performance metrics so that they reflect the new priorities. The maintenance organization should be evaluated on the basis of results or effectiveness, not merely activity. It is much more important to know that the PM program reduced equipment downtime by 25% than to find out that 100% of scheduled PM tasks were completed. The managers must be committed to the change if they hope to get commitment from the workers. They must remember that everyone will be watching them during this time of uncertainty. As the saying goes, "their actions will speak louder than their words", so their behavior must be consistent with their message. They must also be cognizant of the anxieties of the workforce and try to address them. To be successful, management will have to be patient and address individual problems as they arise. Communication and training will be important tools during the change period.

3.6 Evaluate Effects of Solution

The next step is to evaluate the effects of the solution. The evaluation must be made based on the elimination of the original problem. Will the implementation of Planned Maintenance eliminate excessive downtime? Will it produce any new problems or unexpected side-effects? The table below illustrates how the Quality Network Planned Maintenance program addresses each of the suspected causes. All of the suspected causes are covered by at least one of the eleven key elements of QNPM.[20] Full implementation of the Quality Network Planned Maintenance program should eliminate excessive downtime.

Suspected Causes	QNPM Element	Key Features
TECHNOLOGY		
Machine Failure	Maintenance Engineering & Re-engineering	Historical records kept to help identify downtime causes and re-engineer equipment Reliability & Maintainability parameters to be specified for new equipment.
PEOPLE ISSUES		
Downtime Accepted	Financial Control & Monitoring	Establish maintenance goals. Measure performance and communicate plant-wide.
No Commitment to PM	People Involvement & Organization	Joint GM-UAW leadership fully supports continuous improvement of QNPM.
Poor Diagnostic Skills	Training & Development	Complete Training Needs Analysis. Training readily accessible to all personnel.
BUSINESS PROCESSES		
Reactive Maintenance	Maintenance Engineering & Re-engineering	Historical records kept to help identify downtime causes and re-engineer equipment.
Resource Allocation	Scheduled Maintenance	Planning system for all scheduled maintenance. Predictive technologies utilized to detect early stages of failure.
Poor Communications	Communications	Formal communication method established to ensure distribution of accurate information in a timely manner.

Table 3-1 Root Causes and Key Elements of QNPM

[20] See Appendix B for a listing of the Key Elements of QNPM.

3.7 Standardize The Solution and Reflect on Process

This final step requires that you reflect on the entire problem solving process and consider what you have learned. Anything that you think that you could have been done better should be documented and forwarded to the rest of the organization. In addition, any problems that have come up during the process should be explained so that others can avoid them. For example, resistance encountered during implementation should be noted so that subsequent teams will not be caught off guard. The solution should be made the new standard so that the others can benefit from your team's learning. This is a valuable step that must not be overlooked because this is where the knowledge is transferred to the rest of the organization. It is very important to follow the process all the way through this step to get the full benefit of the exercise.

Chapter 4: Conclusions and Recommendations

This chapter provides a brief summary of the results of this research. The first section will include a brief summary of the problem analysis and proposed solution. In the next section are specific recommendations on how to improve body shop performance in a three-crew, two-shift environment. These recommendations represent a collection of best practices observed during the plant visits and recognized world class maintenance principles from various industries. The chapter ends with some general conclusions drawn from the internship experience and the authors final comments.

4.1 Summary of Results

The thesis began with a discussion of what it meant to be World Class. It was suggested that World Class Manufacturers perform at such a high level because they have learned to balance the needs of people, technology and business processes. An integration framework was introduced to illustrate that World Class Manufacturing was the integration of these three management sub-systems. Manufacturing organizations that emphasize any one of the three systems at the expense of the others will not reach their optimal performance level. Likewise, they cannot create the optimal solution to a problem without considering all three management systems. The introduction ended with an outline of the structured problem solving methodology that would be used to analyze the internship problem.

The central issue of the internship project was the impact that the three-crew, two-shift production schedule had on body shop equipment maintenance. The problem solving methodology was used to examine the problem and develop integrative solutions. The primary problem was identified to be excessive equipment downtime, so the objective of the problem solving effort was to reduce maintenance related downtime to zero. Inadequate maintenance and equipment reliability were determined to be the root causes of excessive machine downtime. General Motors' version of Total Productive Maintenance, Quality Network Planned Maintenance, was chosen as the solution to the problem of excessive downtime. QNPM was chosen because it systematically addresses all of the suspected root causes and provides an integrative solution.

4.2 Three-Crew, Two-Shift Recommendations

The following section addresses some of the issue that should be considered by any plant that might be contemplating a move to three-crew, two-shift. These recommendations are based on best practices observed during the plant visits and accepted world class maintenance principles.

4.2.1 Proposed Three-Crew, Two-Shift Schedules

Proposed Production Schedule: The fact that each of the plants was operating under a different schedule than the others suggests that there might not be one best schedule. However, it is possible to point out some of the pros and cons of the various configurations. There are so many issues that need to be considered that it is nearly impossible to prescribe a template three-crew, two-shift schedule, but here are some of the issues to be considered when developing a three-crew, two-shift schedule:

- Whether the crew schedules will be fixed or rotating.
- Ergonomic issues – eating, sleeping, length of shift, rotation, start time, days off.
- Start times that will optimize maintenance windows.
- Contractual overtime agreements.
- Equity among crews.
- Communication issues – with maintenance crews and across production crews.

Proposed Production Schedule

Shifts	Sun	Mon	Tue	Wed	Thu	Fri	Sat
DAYS		A 6:00A - 4:00P	A 6:00A - 4:00P	A 6:00A - 4:00P	A 6:00A - 4:00P	C 6:00A - 4:00P	C 6:00A - 4:00P
NIGHTS	C 7:00P - 5:00A	C 7:00P - 5:00A	B 5:00P - 3:00A	B 5:00P - 3:00A	B 5:00P - 3:00A	B 5:00P - 3:00A	

Figure 4.1 Proposed 3C/2S Production Schedule

The proposed production schedule is essentially the same as the schedule used at Lordstown. The main difference is the start times of the shifts have been changed to try to maximize the maintenance windows. The proposed schedule provides a full hour between the day and night shift to allow for limited production overtime while still giving maintenance enough time to change weld caps and prepare for the next shift. It also provides a three hour window for the maintenance night crew to complete preventive maintenance work. This schedule assumes that a ten hour shift can be negotiated by trading relief time for a paid lunch break. It should also be noted that the C-crew has a later start time for its night shift than the normal start time for B-crew. Starting at 7:00p on Sunday lengthens the weekend maintenance window by two hours, and gives the C-crew more time to rest before switching to night shift.

The proposed schedule was chosen due to the following factors:

- Fixed weekly schedule makes it easier to adapt to physiologically.
- Only C-crew has to rotate from day to night shift.
- Three consecutive days off per week for all three crews.
- All three crews got at least one weekend night (Saturday) off.
- Later start on Sunday allowed C-crew to spend most of day at home with family, and maximized maintenance window.
- Minimizing the gap between day and night shift allows face to face contact with counterpart on other crews and promotes better communication.

Conversations with people at the plants brought out some issues that were not considered initially. Many schedules that seemed to be more "fair" to all of the crews were criticized by people in the plant because they did not provide a clearly preferable shift. Since most crew assignments are determined by seniority, there was a strong desire to make at least one of the crew schedules the best. It was a reward for higher seniority. This was clearly an influence at Lordstown and Moraine (check the Moraine C-crew schedule) but not at Saturn. Saturn's schedule has everyone rotating to ensure fairness or more likely to equalize the pain. This makes sense because seniority is not an important issue at Saturn due to the team ethic and the fact that almost everyone started at the same time so they all have the same seniority. Another issue that turned out to be important was not having to work Saturday night. Originally, the proposal was to start the work week on Monday morning and have all day Sunday for the weekend maintenance window, but the Saturday social time seemed important enough to mirror the Lordstown schedule.

Proposed Maintenance Schedule: Figuring out the best maintenance schedule was more complicated than determining the production schedule. In order to develop the proposed schedule many issues had to be considered and weighed against one another. Here are some of the most important considerations:

- Provide maintenance support whenever production is running.
- Optimize maintenance windows.
- Regular use of weekend for maintenance (incentives to attract volunteers).
- Contractual overtime agreements.
- Ergonomic Issues – eating, sleeping, length of shift, rotation, start time, days off.
- Communication Issues – across crews within maintenance, with production crews.
- Distribution of personnel across shifts (crew size).

During the plant visits many possible schedule variations were suggested and discussed with the managers and trades people to get their input. In developing the schedule, one of the biggest decisions to be made was whether or not the maintenance crews needed to follow the production schedule. This is where a trade-off had to be made between the interests of integration of maintenance and production, and communication and teamwork within the maintenance organization.

The main point in support of having maintenance follow the production schedule was that it promoted communication and teamwork between production and skilled trades. This was important part of establishing a strong working relationship between the two groups. This issue was very important at Moraine because the supervisors had both production and maintenance under their area management system. On the other side of the argument, communication *within* the maintenance department was easier with a more traditional schedule. Having all three crews come in every day promoted communication among the skilled trades crews. Many maintenance personnel argued that this relationship was an essential part of their communication system, and without it things could easily fall though the cracks. In addition, a traditional schedule avoided the coverage problem that can occur between shifts when the maintenance crew leaves with production. When the maintenance schedule mirrors production the between-shift maintenance windows are usually covered with skeleton crews. With a traditional schedule, a full crew can be utilized between shifts. The only problem with a traditional schedule is that the sixth production day needs to be covered – usually with volunteers – but this issue is addressed in the proposed schedule.

Proposed Maintenance Schedule

Shifts	Sun	Mon	Tue	Wed	Thu	Fri	Sat
Day 7:00A - 3:30P		A	A	A	A	A	A
Afternoon 3:00P - 11:30P	B	B	B	B	B	B	
Midnight 11:00P - 7:30A	C	C	C	C	C	C	

Figure 4.2 Proposed Maintenance Schedule

The proposed maintenance schedule has the crews following a traditional three-shift schedule. The main difference is that they now must cover six days of production each week. To provide full coverage for the extra day of production, the proposals is that each of the three crews would be staffed with 120% of a traditional crew and everyone would work 5 of 6 days each week. Everyone would have a rotating day off during the week in addition to the non-production weekend day (Saturday or Sunday). Voluntary overtime would be offered each week to cover the required weekend maintenance window. The specifics on how to administer the rotating day off and how to equalize overtime opportunities would need to be worked out, but in principle this schedule would work. The proposed maintenance schedule preserves the relationships of the traditional schedule while providing full coverage for all production shifts. The major benefit that it provides is that it gives everyone at least one day off per week to rest. Traditionally the incentive of overtime pay for weekend work has been strong enough that many skilled trades people come in six or seven days per week and never properly rest their bodies. Fatigue from lack of rest over an extended period could eventually lead to lower productivity and a higher probability of mistakes and accidents. This schedule would allow everybody to take at least one day off per week.

4.2.2 Body Shop Operating Philosophy

Area Management: Under the time pressures of a three-crew, two-shift schedule it is important that maintenance and production have the same priorities and objectives. Integration of production and maintenance is an important part of performing at a world class level. The most natural way to promote this type of relationship is through area management. It is easier to focus the entire organization on the ultimate goal of the body shop when the area manager controls both maintenance and production. Ideally, the concept could be followed all the way down to the first line supervisor, but this is not always practical. Having the line supervisor cover both maintenance and production can cause a problem if he or she does not have the skill set required to address the technical challenges faced by maintenance. If the supervisors are not adequately trained for their new role, this change can create unexpected problems. For this reason, many plants do not have line supervisors cover both maintenance and production. Fortunately, a majority of the benefits of area management can be achieved by having both functions report to the same superintendent, or at least the same area manager.

Self-Directed Work Teams: Teams are important because many maintenance problems today are too complex to be solved by one person. A strong team can capitalize on the skills and expertise of their different members to become more effective problem solvers. The benefits of self-directed work teams were evident at both Saturn and Antwerp. These teams fostered a more proactive maintenance environment because they were responsible for doing whatever it took to maintain the equipment in their area. For example, in Antwerp each of the teams was responsible for completing all the preventive maintenance for specific set of equipment within their area. (Since they rotated shifts each crew had the four hour PM window provided by the night shift every third week.) The team was then held accountable for any equipment failure that should have been avoided through PM. This accountability gave the team incentive to proactively eliminate potential problems before they resulted in downtime. This resulted in 99% uptime in some areas of the Antwerp body shop.

New Role for Managers: To promote the development of the self-directed work groups, managers must become coaches and advisors rather than overseers. They need to provide assistance and guidance to help develop their employees, and seek input to advance their own development. To become more efficient, the organization needs to fully utilize the skills and abilities of everyone in the department.

Workplace Organization: Workplace organization, or industrial housekeeping is an essential first step in any improvement program. In Japan, the basic principles of industrial housekeeping are known as the Five S's[21]: *Seiri* (organization), *Seiton* (tidiness), *Seiso* (purity), *Seiketsu* (cleanliness), and *Shitsuke* (discipline). The Antwerp plant started its transition to proactive maintenance by focusing on these principles. The Antwerp Body Unit management insisted that this was a necessary as a first step because it builds morale and helps develop a more disciplined organization.

Implementation of QNPM: As suggested in Chapter 3, full implementation of the Quality Network Planned Maintenance program is critical for three-crew, two-shift plants. QNPM provides the focus on equipment efficiency and continuous improvement that is essential for efficient operation in a three-crew, two-shift environment.

4.2.3 Maintenance Organization

Maintenance Mission: The first step toward developing a world class maintenance organization is to clearly define the mission of maintenance. A clear mission statement along with the values and beliefs of the organization should be documented and communicated to everyone. It is important that the mission of the maintenance organization must support the goals and business objectives of the body shop. To support these goals, the maintenance organization must focus on increasing throughput and quality through continuous improvement activities. The mission statement needs to explicitly state these objectives and explain the means by which you plan to achieve them.

Mission Statement: To support the continuous improvement of production quality and throughput by ensuring equipment reliability through the implementation and application of Planned Maintenance.

New Role for Maintenance: In a three-crew environment the maintenance organization must accept a new role. Their new role is focused on capacity assurance rather than repair. This means that individuals will also have the revise the way look at their job. First, the skilled trades persons need to become technicians, rather than fix-it people. They will need to focus more on the technical aspect of the job -- problem solving, root cause analysis, equipment reengineering -- and let the production workers help them by cleaning and inspecting their own equipment. With the time pressures of the three-crew, two-shift schedule there is more than enough work for the skilled trades to complete.

Implement Cross Training: High levels of productivity require some level of cross training or multi-skilling among the skilled trades. It was interesting to note that all three of the NAO three-crew, two-shift plants used the Welder Electrical Machine Repair (WEMR) trade in the body shop. At Saturn, the primary classifications were Electrical and Mechanical, and trades people worked across traditional lines of demarcation. In Antwerp, all of the maintenance mechanics are multi-skilled, with classifications to denote their level of proficiency. The flexibility offered by multi-skilled trades people is particularly important in a three-crew environment, because it can help the maintenance planners utilize resources more efficiently. Ideally, all assembly plants should move toward the Saturn or Antwerp models of multi-skilled maintenance technicians, but this will have to be negotiated into the UAW contract so it is probably not feasible in the near future. As an intermediary step, assembly plants should look to reinstate the WEMR trade within the body shop. (The WEMR trade is still prevalent in GM metal fabrication plants, but no longer found in most assembly plants.)

4.2.4 Maintenance Practices

Reduce Fire Fighting: The most important way to reduce fire fighting is to get a handle on the nature of the downtime that you are seeing. Start by recording and tracking all downtime in a shift. The next step is to look for the most common problems and attack them by using the "Five

[21] See Appendix A for a brief explanation of Five S principles.

Whys"[22] to determine the root cause. The Antwerp plant found that eliminating chronic failures can quickly cut costs and improve productivity.

Review Maintenance Tactics: It is important to work smarter, not harder. Maintenance tactics should be reviewed to make sure that you are optimizing the use of time and your work force. You need to determine if the current preventive maintenance program is having any effect. If you are overwhelmed with too many PM tasks, check to see if they are all necessary. Do you know if you are having fewer breakdowns due to PM? It may be possible to eliminate some of the tasks or at least reduce the frequency. With the time constraints of three-crew, two-shift it is necessary to utilize condition based maintenance tactics where equipment is inspected or monitored and further action is taken based on the condition. This is where predictive maintenance technologies are utilized. Predictive tools such as oil analysis, vibration analysis, thermography, and ultrasonic inspection can be used to determine the condition of the equipment, and to help predict impending failure before it happens. Saturn Body Fab and Lordstown both saw a substantial pay-back for their investment in predictive technologies.

Planning and Scheduling: There are very few actions in maintenance that correlate as strongly with lower costs and higher overall equipment efficiency than professional planning and scheduling. They are usually managed together, but they are two distinct processes. Planning is deciding *what* and *how*, and scheduling is deciding *when* and *who*. In the planning stage, constraint management tools should be utilized to prioritize the projects in order to make the most efficient use of resources. Planning and scheduling are essential tools for increasing maintenance productivity in a three-crew, two-shift operation.

Training Program: Training and education are an important part of any world class organization. Training needs to be looked at as an investment in the organization's most important asset; its people. To get the most value from the investment, maintenance people should be encouraged to take business and leadership classes as well as relevant technical training. Continual teaching and learning should become a regular part of the organization. To

[22] The Five Whys is a Japanese problem solving tool that successively asks the question "why?" to dig down to the root cause of a problem.

emphasize the importance of training, there should be minimum requirements for everybody in the organization, as there is at Saturn.

4.2.5 Re-engineering the Equipment

Maintenance Re-engineering: One of the most important elements of QNPM is maintenance engineering and re-engineering. This is where all of the learning that has taken place through root cause analysis and problem solving gets spread throughout the plant. The goal of re-engineering is continuous improvement. The role of the maintenance organization is to incorporate the new ideas from problem solving into current equipment and to feed this information back to the engineering staff to improve future generations of equipment. The QNPM focus on Reliability and Maintainability will help formalize this important feedback process.

- **Reliability** is the probability that machinery can perform continuously, without failure, for a specified interval of time when operating under stated conditions. Increased reliability implies less failure of the machinery and consequently, less downtime and loss of production.
- **Maintainability** is a characteristic of design, installation, and operation, usually expressed as the probability that a machine can be retained in, or restored to, specified operable condition within a specified interval of time when maintenance is performed in accordance with prescribed procedures.[23]

Central Office Engineering: Engineering can improve productivity in the plant by increasing the reliability and maintainability of the equipment. This is because decisions made during the design stage determine the intrinsic reliability and maintainability of the equipment. It is important that Engineering understands the positive impact that they can make by defining reliability and maintainability requirements during the equipment design stage.

[23] National Center for Manufacturing Sciences. "Reliability and Maintainability Guideline for Manufacturing Machinery and Equipment." 1993.

4.3 Conclusions

The following conclusions outline some of the key learnings drawn from the author's internship experience. These findings are not specific to three-crew, two-shift plants, they actually apply to any manufacturing organization that is striving to become a World Class competitor.

- ***Integration is key to World Class Manufacturing.***

Learning to integrate people, business processes, and technology issues is an essential part of becoming a World Class organization. A purely technical approach rarely provides the optimal solution to any manufacturing problem. Maintenance is essentially a people process. In the plant, issues such as housekeeping and reactive maintenance must be addressed before the full benefits of technological tools like computerized maintenance management systems can be enjoyed.

- ***Plants must focus on eliminating waste.***

The entire organization must focus on continuous improvement of equipment and processes to find and eliminate waste. In the body shop, downtime is the primary form of waste. The entire body shop culture needs to be changed; downtime cannot be accepted as an inevitable problem. The maintenance organization must consider recurring failures as shameful, and must work together with production to eliminate these chronic losses.

- ***There is a need for strong, consistent leadership from management.***

Strong, consistent leadership is necessary to successfully implement long term improvement projects like Planned Maintenance. When managers are changed there must be a consistent message defining the organization's priorities. The tendency to jump onto new ideas and throw away past systems every time plant management changes must be stopped. Meaningful change takes time; the organization cannot make significant improvements if its priorities are changed with every new management regime.

4.4 Final Comments

The main theme running through this thesis is that most manufacturing organizations need to change their approach to approach problem solving if they aspire to become World Class. It is suggested that an integrated approach, one that considers people issues, business processes, and technology systems, will produce the most complete solutions to manufacturing problems. Technical solutions are not the answer to every manufacturing problem. The issue of maintenance in a three-crew, two-shift environment is a good example of this point. Several of the root causes of body shop equipment reliability problems can be attributed to people issues and business practices such as reactive maintenance rather than to the actual equipment. In this case, the attention of management must be focused on moving the culture toward proactive maintenance rather than looking for technical answers. Once these issues have been addressed, the overall system performance can be optimized with technology. In conclusion, it is hoped that this thesis will serve as a guide for General Motors and other companies to the benefits of taking an integrative approach toward resolving manufacturing problems. At the very least, it should provoke thought and discussion about the potential hazards of focusing on technical solutions too quickly.

Bibliography

Avery, Susan. "World Class Redefines the Role of Maintenance," *Purchasing.* Vol. 114, No.4, March 18, 1993, p.58.

Blache, Klause M., and Anil B. Shrivastiva. "Reliability and Maintainability of Machinery and Equipment for Effective Maintenance." *SAE Technical Paper Series, #930569.* Warrendale, PA: Society of Automotive Engineers, 1993.

Blache, Klause M., and Anil B. Shrivastiva. "Defining Failure of Manufacturing Machinery and Equipment." *1994 Proceedings Annual Reliability and Maintainability Symposium.* 1994.

Cambell, John Dixon. *Uptime: Strategies for Excellence in Maintenance Management.* Portland OR: Productivity Press, 1995.

Goldratt, Eliyahu, and Jeff Fox. *The Goal.* Croton-On-Hudson, NY: North River Press, 1984.

Goldratt, Eliyahu, and Jeff Fox. *The Race.* Croton-On-Hudson, NY: North River Press, 1986.

Herbaty, Frank. *Handbook of Maintenance Management: Cost Effective Practices.* Park Ridge, NJ: Noyes Publication, 1990.

Hirano, Hiroyuki. *Putting 5-S to Work: A Practical Step by Step Approach.* New York: PHP Institute, 1993.

Levitt, Joel. *Managing Factory Maintenance.* New York: Industrial Press, 1996.

Moubray, John. *Reliability Centered Maintenance.* Oxford, England: Butterworth-Heinemann, 1991.

National Center for Manufacturing Sciences. "Reliability and Maintainability Guideline for Manufacturing Machinery and Equipment." 1993.

Nakajima, Seiichi. *Introduction to TPM: Total Productive Maintenance.* Cambridge MA: Productivity Press, 1988.

Nakajima, Seiichi (editor). *TPM Development Program: Implementing Total Productive Maintenance.* Cambridge MA: Productivity Press, 1989.

Ohno, Taiichi. *Toyota Production System: Beyond Large Scale Production.* Cambridge MA: Productivity Press, 1988.

Ohno, Taiichi. *Workplace Management.* Cambridge MA: Productivity Press, 1988.

Recardo, Ronald J., and Luigi A. Peluso. *The People Dimension: Managing the Transition to World-Class Manufacturing.* White Plains, NY: Quality Resources, 1992.

Robinson, Charles J., and Andrew P. Ginder. *Implementing TPM: The North American Experience*. Portland, OR: Productivity Press, 1995.

Schreffler, Roger. "Total Productive Maintenance," *Automotive Industries*. Vol. 176, No. 11, November 1996, pp. 67-69.

Senge, Peter M. *The Fifth Discipline*. New York: Doubleday, 1990.

Shiba, Shoji, Alan Graham, and David Walden. *A New American TQM: Four Practical Revolutions In Management*. Portland, OR: Productivity Press 1993.

Takahashi, Yoshikazu, and Takashi Osada. *TPM: Total Productive Maintenance.* White Plains, NY: Quality Resources, 1990.

"Technology Trends: Developments in TPM." *Motor Business Japan.* The Economist Intelligence Unit, 3rd Quarter 1996, pp. 63-71.

Todd, Jim. *World Class Manufacturing*. London: McGraw-Hill International, 1995.

Tsuchiya, Seiji. *Quality Maintenance: Zero Defects Through Equipment Management*. Cambridge MA: Productivity Press, 1992.

Weekley, Thomas L., and Jay C. Wilbur. *United We Stand: The Unprecedented Story of the GM-UAW Quality Partnership*. New York: McGraw-Hill, 1996.

Winter, Drew. "Bending Time: Three-crew Schedules Put an All-new Face On the Clock," *Ward's Auto World.* May 1995, pp. 34-36.

Womack, James P., Daniel T. Jones, and Daniel Roos. *The Machine That Changed the World.* New York: Harper Perennial, 1991.

APPENDIX A: The Principles of the Five S's [24]

In Japan, the basic principles of industrial housekeeping are known as the Five S's: Seiri (organization), Seiton (tidiness), Seiso (purity), Seiketsu (cleanliness), and Shitsuke (discipline). The basic idea of the program is simplicity: by keeping things orderly an d clean, it is possible to increase efficiency. The Japan Institute for Plant Maintenance (JIPM) claims that manufacturers can achieve dramatic results in efficiency, quality, and safety by devoting five minutes before each shift to Five S activities. Five S creates order and instills a sense of discipline on the factory floor.

1. ***SEIRI*** -- *Clearing Up:* This step amount to sorting tools and equipment by frequency of their use. Those with high frequency (hourly to daily usage) should be carried by the employee or kept at the job site. Those with average frequency (weekly to monthly usage) should be stored in the factory. Those with low frequency (yearly usage) should be thrown away or stared away from the job site.

2. ***SEITON*** -- *Organizing:* Involves workplace organization so that tools and equipment are laid out to be available as needed, otherwise too much time is wasted searching for tools due to poorly organized shelves. The basic steps to improved organization of the workplace are: analyze the present situation; fix storage places; set a storage method; and rigidly adhere to storage rules. In organizing the workplace, JIPM urges ridding the premises of unnecessary items, deciding on a cost and time-effective layout, and standardizing all names. The idea is to keep the stock low without causing stoppages and delays.

3. ***SEISO*** -- *Cleaning:* This step aims at creation of a spotless workplace. Through regular cleaning, plant workers are able to detect all sorts of minor defects including those due to wear. Much of this work is visual, and by taking immediate corrective measures (JIPM claims that the main cause of equipment breakdowns is gradual deterioration), the risk of equipment breakdown or accident is reduced.

4. ***SEIKETSU*** -- *Standardizing:* Aims to institute a system to detect major categories of malfunctions or abnormality points. According to JIPM, the key to success is visual control: defining crucial check points; determining what constitutes a malfunction; deciding if the malfunction will be noticed; and choosing the appropriate remedial action. This all must be done through a standardized approach to ensure consistency.

5. ***SHITSUKE*** -- *Training and Discipline:* To form a habit to follow the rules and procedures. To monitor and continuously improve housekeeping and workplace organization.

---

[24] "Technology Trends: Developments in TPM." *Motor Business Japan*, The Economist Intelligence Unit, 3rd Quarter 1996, pp. 64-65.

APPENDIX B: GM-UAW Quality Network Planned Maintenance

Planned Maintenance is a total systems approach to maintenance involving all employees to increase throughput and uptime, improve quality of output, reduce maintenance costs, and improve safety by continuously improving equipment operation. It is a comprehensive planned maintenance system that includes preventive and predictive scheduled maintenance programs as well as strategies for responding to machinery and equipment failures.

The Eleven Key Elements of Planned Maintenance:

1. People Involvement & Organization
2. Financial Monitoring & Control
3. Spare Parts
4. Training & Development
5. Communications
6. Emergency Breakdown Response
7. Scheduled Maintenance
8. Construction Work
9. Facilities & Equipment
10. Maintenance Engineering & Re-engineering
11. Housekeeping